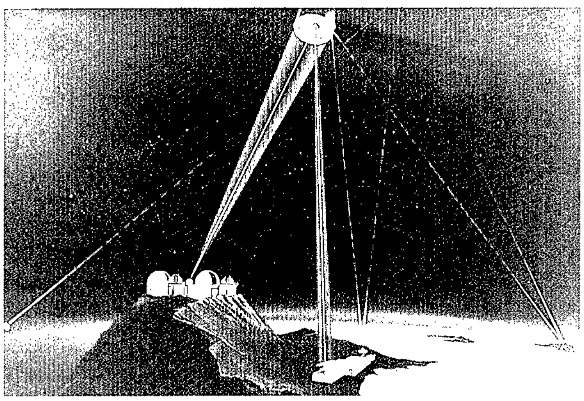
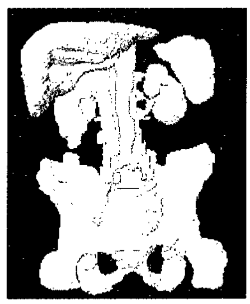
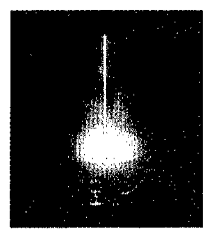
SDI

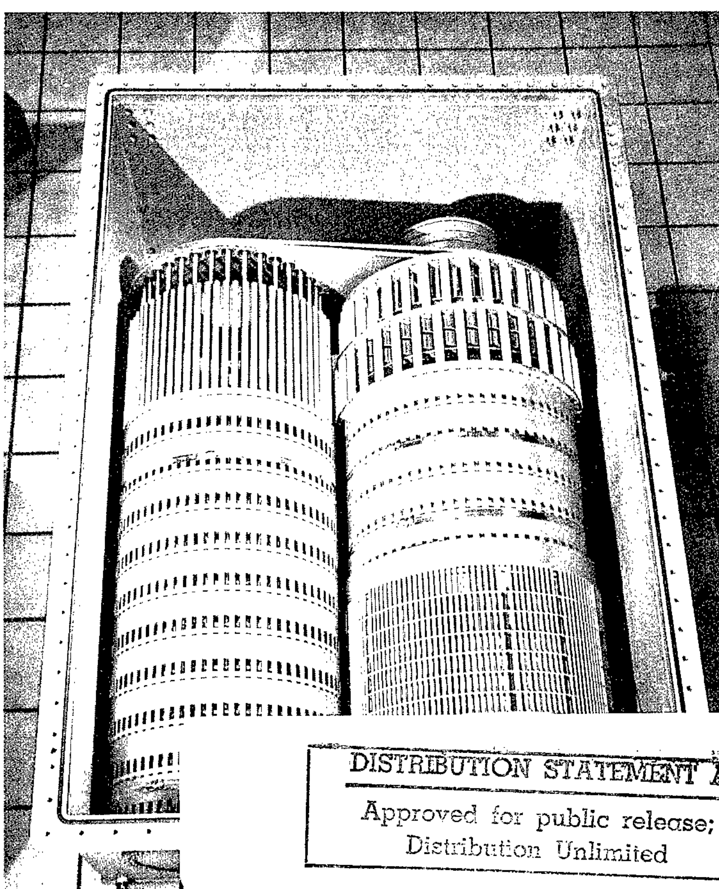
Strategic
Defense
Initiative

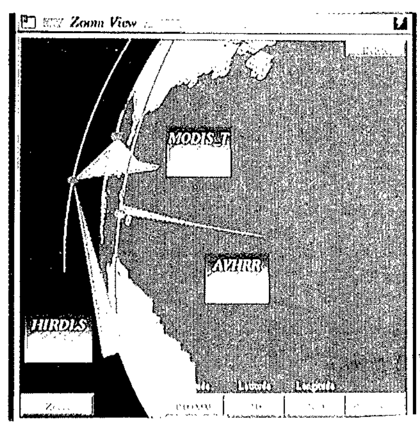
Technology Applications Report

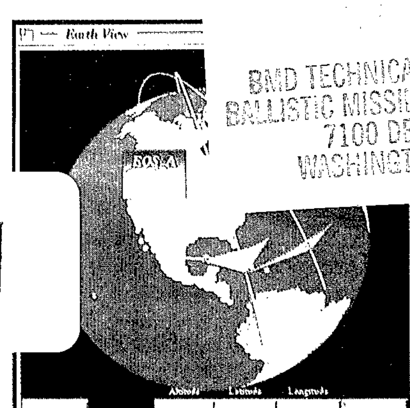












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On the Cover:
The background photo of a remote plasma chemical vapor deposition (RPCVD) chamber was provided courtesy of the University of Texas at Austin's Department of Electrical and Computer Engineering. More information about the RPCVD chamber can be found on page 45.

The following list gives the name of the organization that developed each technology shown in the foreground pictures and the page where more information can be found on them.

Front cover, clockwise from top left-hand corner:

- Applied Technology Associates, Inc. — page 29
- Kensal Consulting — page 11
- Physical Optics Corporation — page 39
- Photon Research Associates, Inc. — page 14
- Science Research Laboratory, Inc. — page 6

Back cover, clockwise from the top right-hand corner:

- Physical Optics Corporation — page 39
- The Charles Stark Draper Laboratory — page 30
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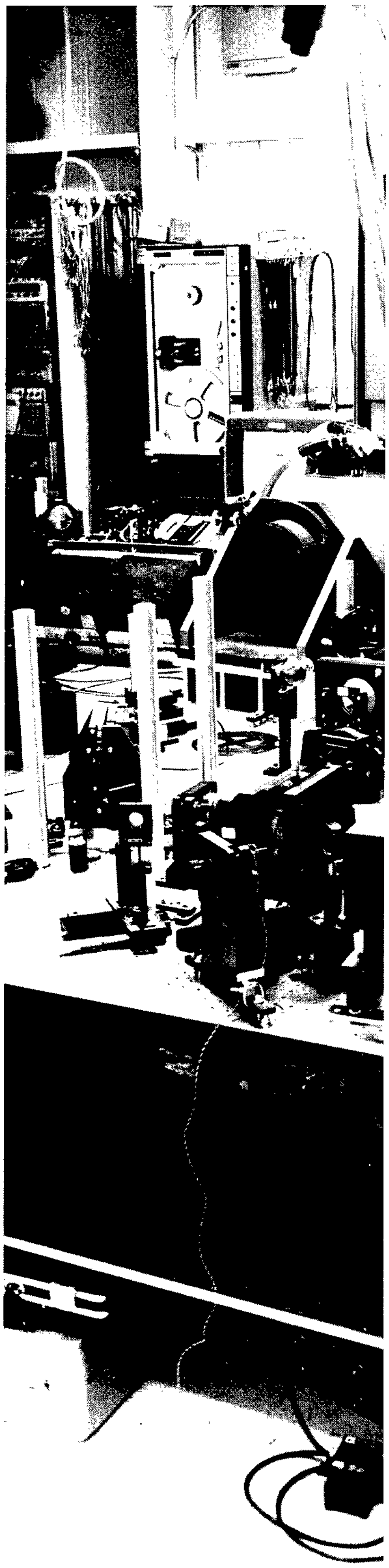
AUGUST 1992



FOREWORD

In transferring technology from one application to another, cooperation between people is as important as technical expertise. The Strategic Defense Initiative Organization (SDIO) Office of Technology Applications offers technology users both: a vast storehouse of technical expertise and a history of working with universities, industry, and federal laboratories. By closely working with these communities, the SDIO Office Of Technology Applications can successfully guide American businesses in need of new technology through unfamiliar cultures.

With legislation now in place encouraging the transfer of federal technology, the cultural differences between government, industry, and academia inhibit the transfer of technology more than anything else. For the past six years, we have been learning how to work with each group and how to gain their trust. Now, with every successful transfer of SDI technology, we attract more people to our program. As a result, spinoffs from SDI research and development are snowballing, introducing more new products and processes to the American economy each year.

We hope the success stories in this report will encourage you to come to us to identify technologies for developing new, or improving existing, products. If you have any questions about a technology or service mentioned in this report, or if you just want to explore ideas about how we can help you, please call the SDIO Office of Technology Applications at (703) 693-1563.

Sincerely,

NICK MONTANARELLI
Deputy Director for Technology Applications

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Industry

Military, Security, and Aerospace

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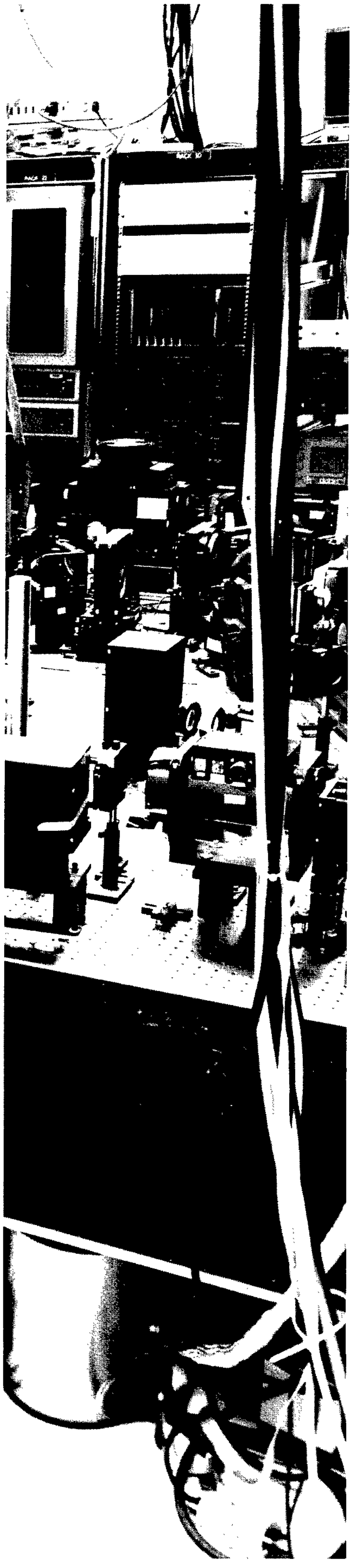


INTRODUCTION
Commercializing Strategic Defense Initiative Technology

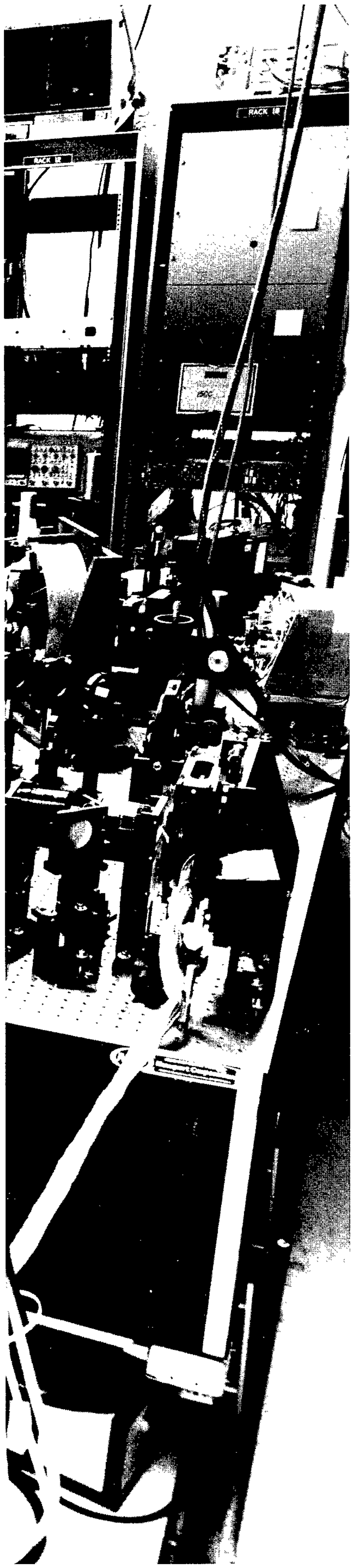
By creating new products, improving existing products, and making manufacturing processes more efficient, new technologies can improve our standard-of-living and create or save millions of jobs. Without technological advances, America will face economic stagnation as the rest of the world races to gain new markets. As a result, the United States needs a continuous flow of new inventions and process refinements to fuel its economic engine. And when business is looking for technological innovations, the Strategic Defense Initiative (SDI) can provide some of that fuel. Each year, as SDI research and development programs mature from basic research to product identification, more and more SDI-sponsored technologies are getting ready to enter the marketplace.

Examples abound, with more than 50 technologies highlighted in this year's report alone. But while the technology exists, SDI and industry must work together to commercialize it. Private companies need to know what technologies SDI has before they can use them, and SDI is making sure they can find out. The SDI Organization's (SDIO's) Office of Technology Applications runs an on-line database, the Technology Applications Information System (TAIS), that is open to American corporations and citizens free-of-charge. The database contains nearly 2,000 abstracts of SDI-funded technologies, and is continually updated and expanded to include new developments in SDI research. By requesting more information on a technology, the TAIS refers users to the SDI researchers involved with the technology. This first-hand access to a technical expert helps users commercialize the research (see the conclusion of this report for information about how to become a TAIS user).

The SDIO Office of Technology Applications also publicizes available technologies to encourage business arrangements that produce spinoffs. Publications include the *SDI High Technology Update*, a quarterly newsletter provided free-of-charge, and this *SDI Technology Applications Report*, an annual report (also free-of-charge) that describes SDI's technology transfer program and highlights representative SDI spinoff successes.

Furthermore, the Office of Technology Applications co-sponsors approximately eight technology applications reviews a year to identify commercial and new governmental applications of SDI technology. Each review focuses on a different technology area (such as biomedical, optics, materials, electronics, or power) and brings together public and private sector experts to discuss commercialization strategies for SDI technologies. After each review, the Office follows through on promising strategies to foster spinoffs that will benefit the nation's economy.

Finally, the Office of Technology Applications has a proactive outreach program designed to work with professional and government organizations such as the National



Technology Transfer Center, the Federal Laboratory Consortium for Technology Transfer, NASA, and many other organizations that share the goal of improving America's economic well-being by introducing new technology into the marketplace.

While these activities comprise the core of the Office of Technology Applications' function, SDI also tests general models of technology transfer to determine how best to transfer technologies in given situations. Ongoing demonstration projects include:

- **Industry-University Cooperation**. Through sponsorship from the Office of Technology Applications, Technology Assessments and Transfer, Inc. and Oklahoma State University are working together to interest the U.S. machine tooling industry in diamond-coated machine tool inserts (such as a drill bit). Diamond-coated inserts, made through a low-cost diamond coating technique developed for SDI, are stronger than other machine tool inserts and experience less friction and wear.

- **State Economic Development Program Interface (New Mexico)**. The Office of Technology Applications is working with state government and federal laboratory officials in New Mexico to identify and commercialize SDI technologies developed at Los Alamos National Laboratory, Sandia National Laboratories, and the Air Force's Phillips Laboratory. The University of New Mexico's School of Business is supporting this technology transfer project by performing market analyses of selected technologies. This is one of the first concerted efforts in the nation to get federal labs, state officials, and university business schools to work together to commercialize promising technologies.

- **State Economic Development Program Interface (Maryland)**. The Office of Technology Applications is working with the State of Maryland and the University of Maryland to assist Maryland companies in commercializing SDI technologies. This project will further develop the model for working with state economic development agencies as formed in the New Mexico project.

- **Superconducting Magnetic Energy Storage (SMES) Technology Assessment**. SDI is analyzing SMES technologies for their technology transfer potential (see page 23 for more information about SMES). This should produce a technical taxonomy of SMES components, track future SMES development, and enhance its transfer to other programs.

- **Civilian Applications of SDI Accelerator Technology**. SDI is documenting its contributions to state-of-the-art accelerator technology. By documenting these advances, the project should help spur commercialization of this technology.

- **Medical Research Technology Transfer**. In this two-phase project, the Office of Technology Applications is reviewing the results of medical research funded by the SDI Medical Free-Electron Laser (MFEL) program to document and promote the program's most significant successes.

- **Business Trade Show Exposition.** The Office of Technology Applications helped a small company exhibit an accelerator, which was funded by the SDI Positron Emission Tomography (PET) program, at a nuclear medicine trade show. Because marketing is such a crucial component in commercializing technology, this project provided the Office with useful experience to help other small firms market their promising technologies.

- **Professional and Trade Association Interface.** The Office of Technology Applications' outreach staff is developing methods to transfer technology through professional and trade associations by identifying conduits for reaching association members and constituents.

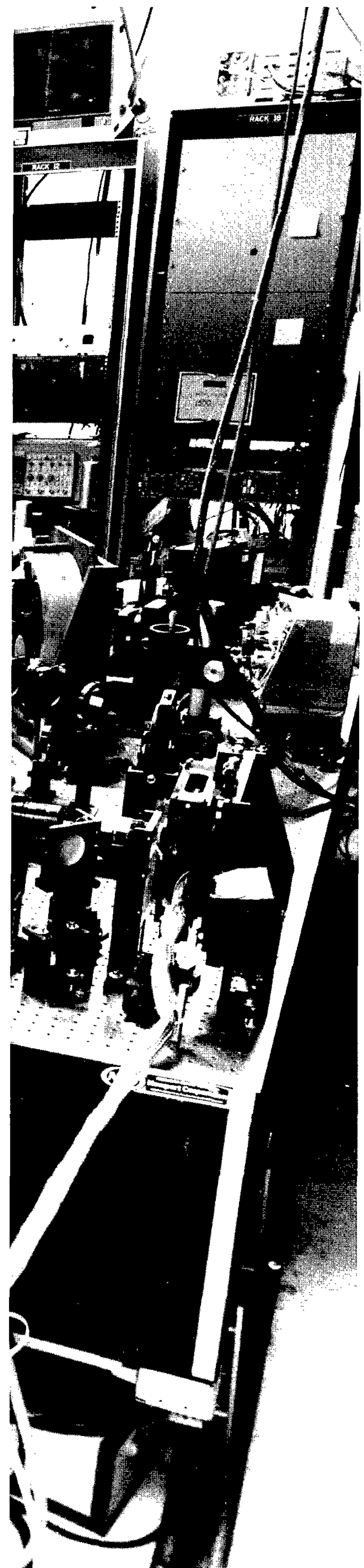
All of SDI's technology transfer activities are building a spirit of cooperation between SDI research programs and industry that helps foster commercialization. This cooperation is paying off particularly with small businesses. Three participants in SDI's Small Business Innovation Research (SBIR) program placed in the *1991 Inc. 500: America's Fastest Growing Private Companies*. For this list, *Inc.* magazine picks the 500 fastest growing firms of the year from over 21,000 eligible companies.

Physical Optics Corporation, ranked 149 on the *Inc.* list, specializes in optics and optoelectronic technologies. Physical Optics is a leader in holographic technology and has commercialized an ultraviolet Raman edge filter in both standard and custom wavelengths. Physical Optics also has developed a polymer waveguide technology used in optical computing.

AccSys Technology, ranked 206, manufactures linear accelerator systems. AccSys has commercialized the Radio Frequency Quadrupole linear accelerator (RFQ linac), which was developed for SDI's Neutral Particle Beam program. AccSys has incorporated its RFQ linac into a proton beam cancer treatment facility at the Loma Linda Medical Center in California, and recently won a contract to build four drift-tube linac tanks for the Superconducting Super Collider.

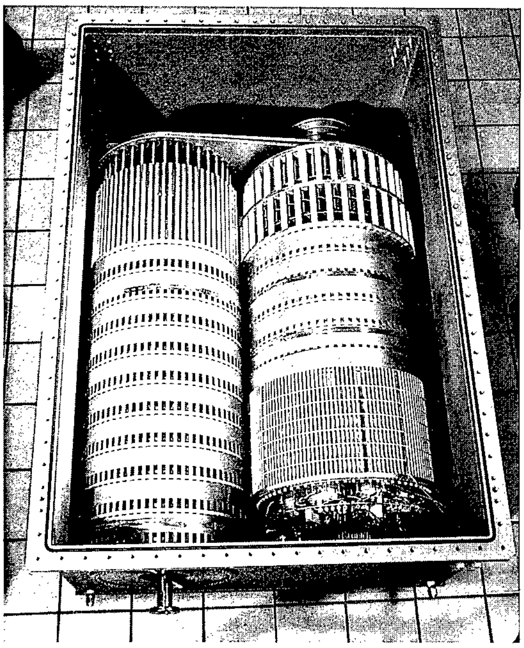
The third company, AstroPower, Inc., is developing solar cells for SDI with commercial space and terrestrial applications. AstroPower, ranked 364, also has developed ultra-bright light emitting diodes (LEDs) through SDI SBIR contracts. These LEDs could provide brighter automobile brake lights that following drivers would notice more quickly than conventional brake lights, cutting driver reaction time by a fifth of a second.

These are by no means the only successful SDI SBIR firms. Firms that have won at least one SDI SBIR contract in two different years have averaged 48 percent growth, far above any growth that can be explained strictly by the infusion of government money. These high tech firms — and others taking advantage of SDI research — are now selling new or improved products, creating jobs, and helping to improve the American economy. They are, by developing spinoff applications for SDI-sponsored research, keeping the engine running.



SDI SPINOFFS Health

Medical Products Sterilized with Compact, Reliable Accelerator



SNOMAD IV modules developed by Science Research Laboratory during an SDI SBIR contract (above and below). The modules, which are about one meter long, could be stacked together in accelerators made to sterilize medical products, reduce sulphur and nitrogen oxide emissions in coal-fired power plants, irradiate food, and weld submarine hulls.

Science Research Laboratory (SRL), Inc.'s (Somerville, MA) SNOMAD IV, a one megawatt electron beam accelerator developed under SDI SBIR contracts, is now in a position to enter the market as a method for sterilizing medical products. Medical products are most commonly sterilized using x-rays produced by the radioactive isotope cobalt 60. The SNOMAD IV — with its reliability, low cost, and compact size (see sidebar) — could sterilize medical products less expensively than x-rays from cobalt 60, and eliminate safety concerns over the radioactivity of cobalt 60.

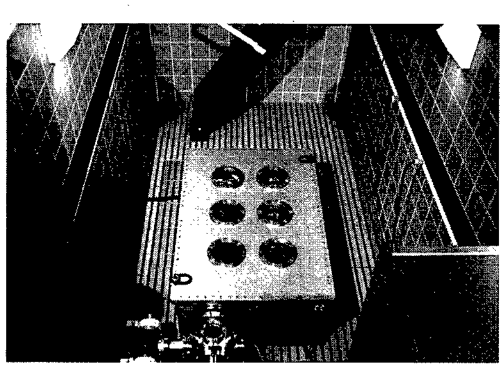
The SNOMAD IV, which was developed for SDI to power free-electron lasers used as directed energy weapons, also could produce electron beams to:

- Reduce emissions of sulphur and nitrogen oxide in coal-fired power plants by converting these hazardous emissions (which cause acid rain) into the common fertilizers ammonium sulfate and ammonium nitrate.

- Treat ground and waste water contaminated with toxic wastes by breaking toxic substances into atomic fragments, which afterward recombine into simpler, non-toxic substances.

- Provide a safe, non-toxic, non-nuclear method for irradiating meats, fruits, vegetables and other perishable foods to prevent them from spoiling.

- Weld several types of materials, including HY100 (a high-strength steel used primarily in submarine hulls), aluminum, stainless steel and titanium. Unlike conventional electron beam welding, this process can be done at atmospheric pressure, which eliminates the need for a vacuum chamber and makes welding aircraft carrier deckplates, nuclear power plant facilities, and other large-scale projects much less expensive.



The following improvements in SRL's SNOMAD IV over existing particle beam device technology increase reliability and simplify operation, thus reducing operational costs. The SNOMAD IV:

- Has an all solid-state driver. The solid-state driver dramatically increases reliability, allowing the SNOMAD IV to operate for two to three years (generating 10^{11} to 10^{12} electron-beam "shots") without routine maintenance, unlike other accelerators that must be serviced every few months when operating under the same conditions.

- Is easy to service. Because of its modular construction (six modules are used to sterilize medical products), a spare module could easily replace a module that required service. As a result, mechanical breakdowns can be repaired with minimal downtime.

- Is easy to operate. With a completely computerized control panel that allows a technician to enter the electron beam's power, current, and run-time, the SNOMAD IV reduces labor costs by eliminating the need for a staff of highly trained accelerator physicists.

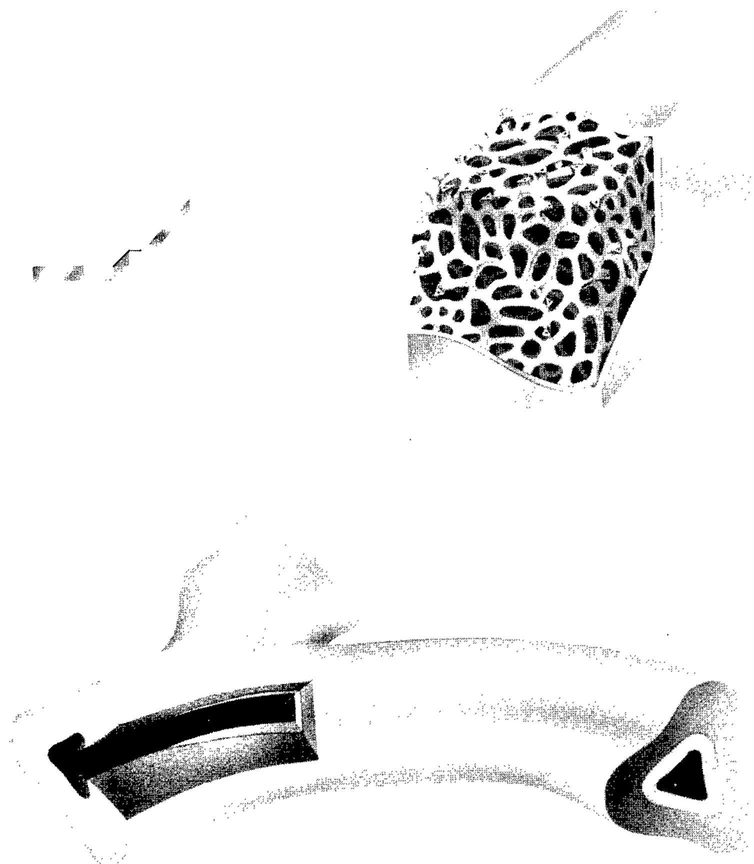
In addition, the SNOMAD IV produces higher average currents than competing radio frequency (RF) and electrostatic accelerators. The higher currents allow the accelerator to operate at optimal beam energies (8 MeV) without sacrificing throughput (average power). Beam energies much higher than 8 MeV are undesirable because medical products, when subjected to beam energies greater than 10 MeV, can become permanently radioactive. Because other accelerators have low average currents, they must sacrifice throughput to operate below this 10 MeV maximum (see Figure 1 below).

Characteristics	SNOMAD IV (using six modules)	RF Accelerators	Electrostatic Accelerators
Average Power* (throughput)	1 megawatt	50 kilowatts	200 kilowatts
Beam Energy (measures penetration)	8 MeV	10 MeV	5 MeV
Average Current	0.125 amps	0.005 amps	0.04 amps
Capital Cost	$2.5 million ($400,000/ module)	$3.5 - 4 million	$1.5 - $4 million

* average power = beam energy x average current

Figure 1: SRL's SNOMAD IV and competing electron beam accelerators

Hip Implant Maker Licenses SDI Rocket Insulating Material



An artist's conception of Ultramet's carbon foams. The top drawing shows the entire foam structure, while the bottom drawing shows an individual fiber.

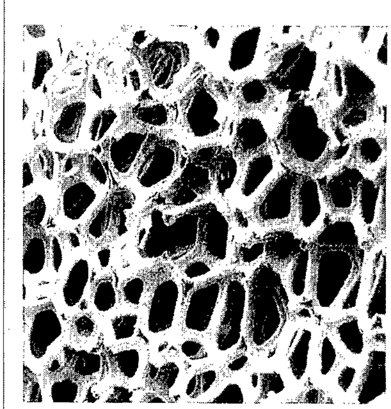
Under SDI SBIR contracts, Ultramet, Inc. (Pacoima, CA) developed structural foams to insulate hot gas nozzles in rockets. On January 24, 1992, Implex Corporation (a spinoff from the third largest hip joint manufacturer in the U.S.) signed a license agreement to use Ultramet's structural foams for musculoskeletal applications. Because Ultramet can tailor the foam's properties by depositing different materials on the carbon foam matrix (see sidebar), the foam can provide an excellent biocompatible matrix structure to promote bone growth. Preliminary tests at Clemson University on goats have shown that the foams enhance and accelerate bone growth better than any material now in use. The National Institutes of Health also has awarded Ultramet a grant to investigate these foams for use in musculoskeletal and dental applications.

Because Ultramet can tailor the properties of their coated carbon foams, the foams have a variety of applications. For example, Ultramet's foams insulate against temperatures 500° C greater than what NASA's Space Shuttle tiles can withstand, thus generating interest from the Air Force in using the foams to insulate its rocket hot gas nozzles. Ultramet sells foams in smaller specialty markets, such as high-temperature filters for pollution control, while the foams also have structural applications in the building construction and aerospace industries.

Man-made cellular materials — similar in structure to natural materials such as wood, cork, sponge, coral, and bone — are replacing natural or traditional materials in environments where traditional materials cannot perform as desired. These new cellular structures, composed of ceramic, metal, and glass, are used for a variety of structural and insulation purposes, or to absorb kinetic energy.

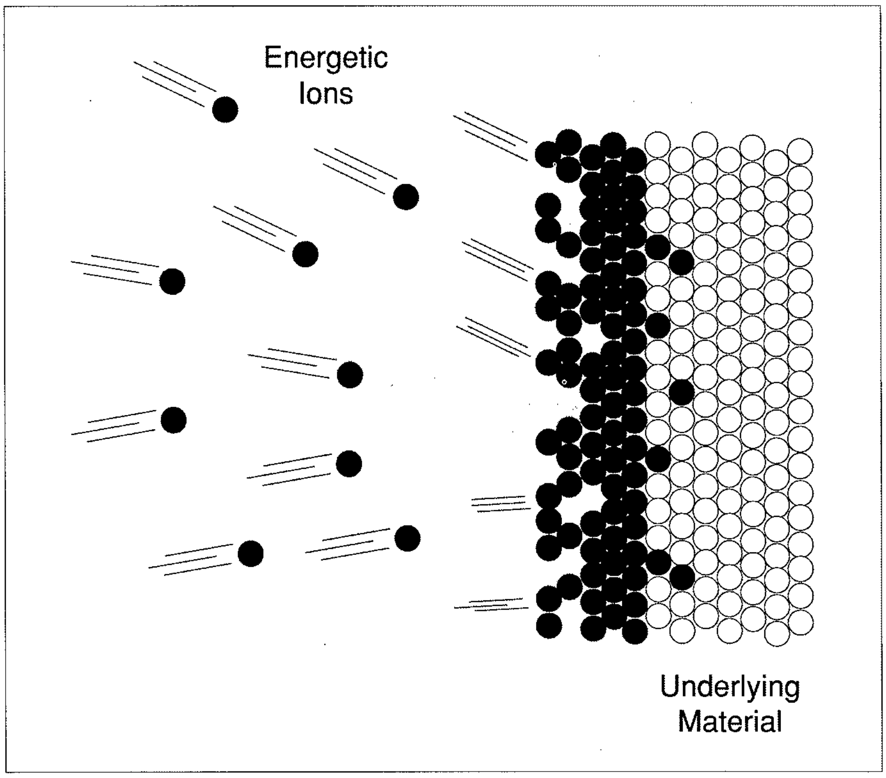
Ultramet has developed a process to tailor its own cellular materials to a variety of applications. With higher chemical purity, higher thermal stability, and lower density than non-porous materials, Ultramet's materials also are lower in cost than competing materials. Furthermore, Ultramet can control the materials' rate of thermal expansion, and make them resistant to oxidation and thermally induced stress and shocks.

Ultramet produces coated carbon foams by making a skeleton material of carbon foam. The company then uses chemical vapor infiltration to deposit different materials, such as silicon carbide or rhenium, on all surfaces of the carbon skeleton. The deposited material encapsulates or coats each element of the skeleton to form a monolithic foam. This coating, rather than the carbon skeleton, establishes the mechanical, thermal, electrical, chemical, and physical properties of the foam while enhancing structural integrity. Ultramet can now coat the foams with over 150 different materials using a manufacturing process flexible enough to produce hybrid, layered, or graded foams.



An optical micrograph of a coated carbon foam that Ultramet, Inc. developed during SDI SBIR contracts.

Surgical Implants Improved with Ion Beam Texturing



In ion beam texturing, a process developed by the Spire Corporation under SDI SBIR contracts, particle accelerators shoot beams of charged particles (ions) onto a material. The ion beams bond to the material to create intricate micron-thick features (hundreds of times thinner than a strand of hair) on metal surfaces. The intricate features on the surface of the material dramatically increase the metal's surface area.

SDI awarded the Spire Corporation (Bedford, MA) SBIR contracts to use ion beam texturing (see sidebar) to treat the surface of optical baffle materials, which increases the pointing accuracy of advanced sensors by rejecting stray light. Ion beam texturing also can change the surface features of materials to make them more compatible with human tissue. Because of this feature, Spire is now making medical devices such as surgical implants, artificial hips and knees, and cardiac pacemaker electrodes with the technique. By increasing the surface area of materials, ion beam texturing provides additional contact area for implants to attach to bone and surrounding tissue. In the case of cardiac pacemakers, ion beam texturing also decreases contact resistance, thus tripling the lifetime of the pacemaker battery.

In another medical application, Spire has experimented with a technique to repair the skin of catastrophic burn victims. In the technique, Spire uses ion beam texturing to treat a surface sheet. Initial research shows that the treated sheets, when placed on burns, should promote skin cell growth over the burn.

Spire also has used ion beam texturing to make telescope baffles and solar radiators for cooling spacecraft. Previously, telescope baffles were treated with anodized acid-bath aluminum, which was easily damaged by handling and vibration. Ion beam texturing creates a surface that is harder and darker than aluminum, thus making it more difficult to damage the baffle surface. Finally, by increasing surface area, ion beam texturing creates solar radiators that provide faster and more efficient cooling.

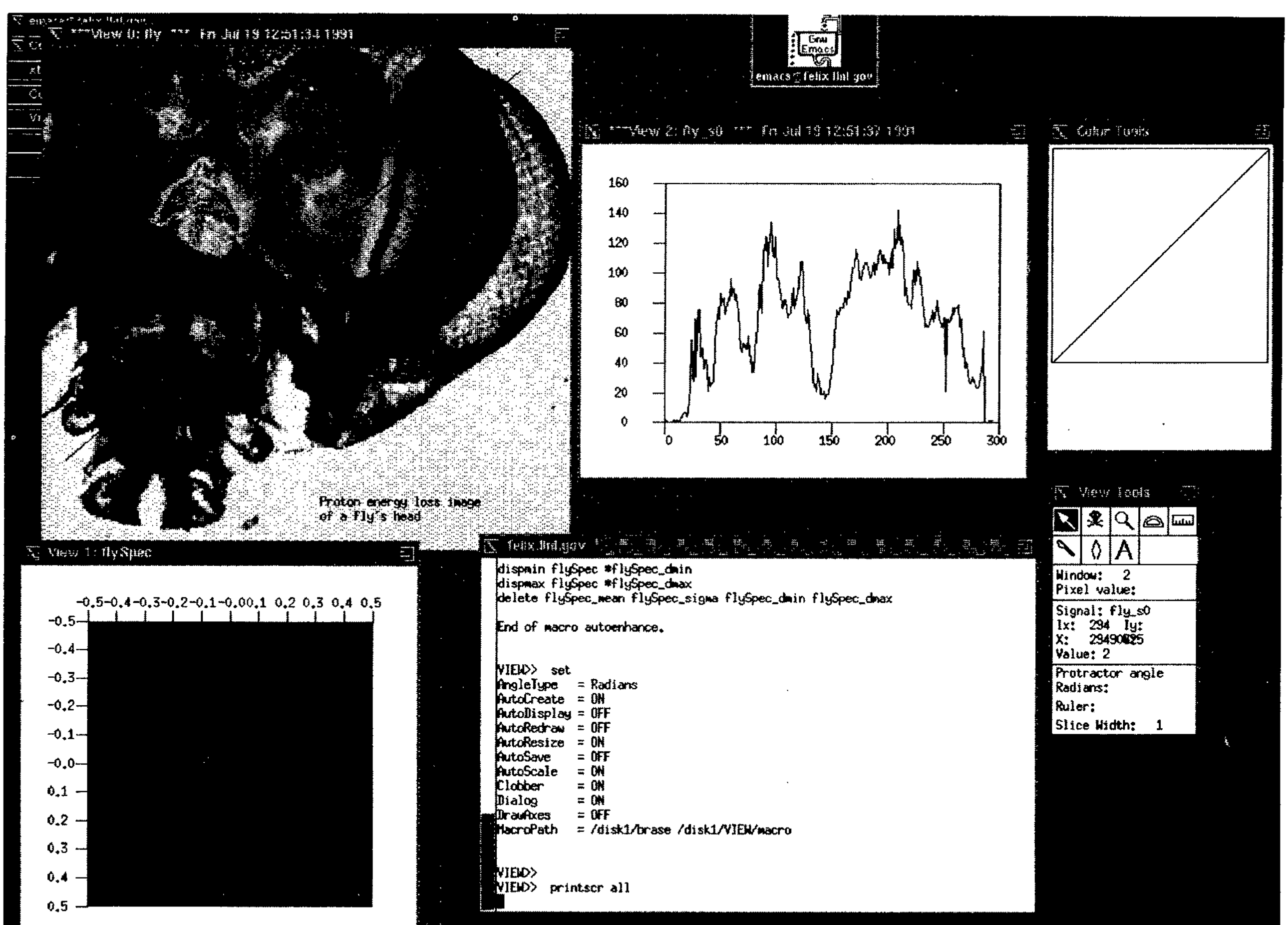
Medical Imaging, Materials Analysis with SDI Target Tracking Software

Image processing software developed at Lawrence Livermore National Laboratory (LLNL) (Livermore, CA) to perform target tracking for SDI and to process images for non-destructive materials testing has been applied to new uses such as medical imaging, materials analysis, and information coding and decoding. The program, called "View," specializes in cleaning up ambiguous data.

Cell biologists at the European Molecular Biology Laboratory have used View to enhance images of cells and chromosomes and to help compare different cellular images. In addition, the University of California at Los Angeles School of Medicine is using View to study brain function, anatomy, and development; Therma-Wave (Fremont, CA) uses View to detect defects in semiconductors; Boeing Aerospace and Electronics has used the program to analyze computed tomographic images of composites, aluminum casings, steel gear assemblies, electronic circuit boards, relays, and transformers; and AT&T Bell Laboratories researchers are using View to code and decode information images sent over transmission lines.

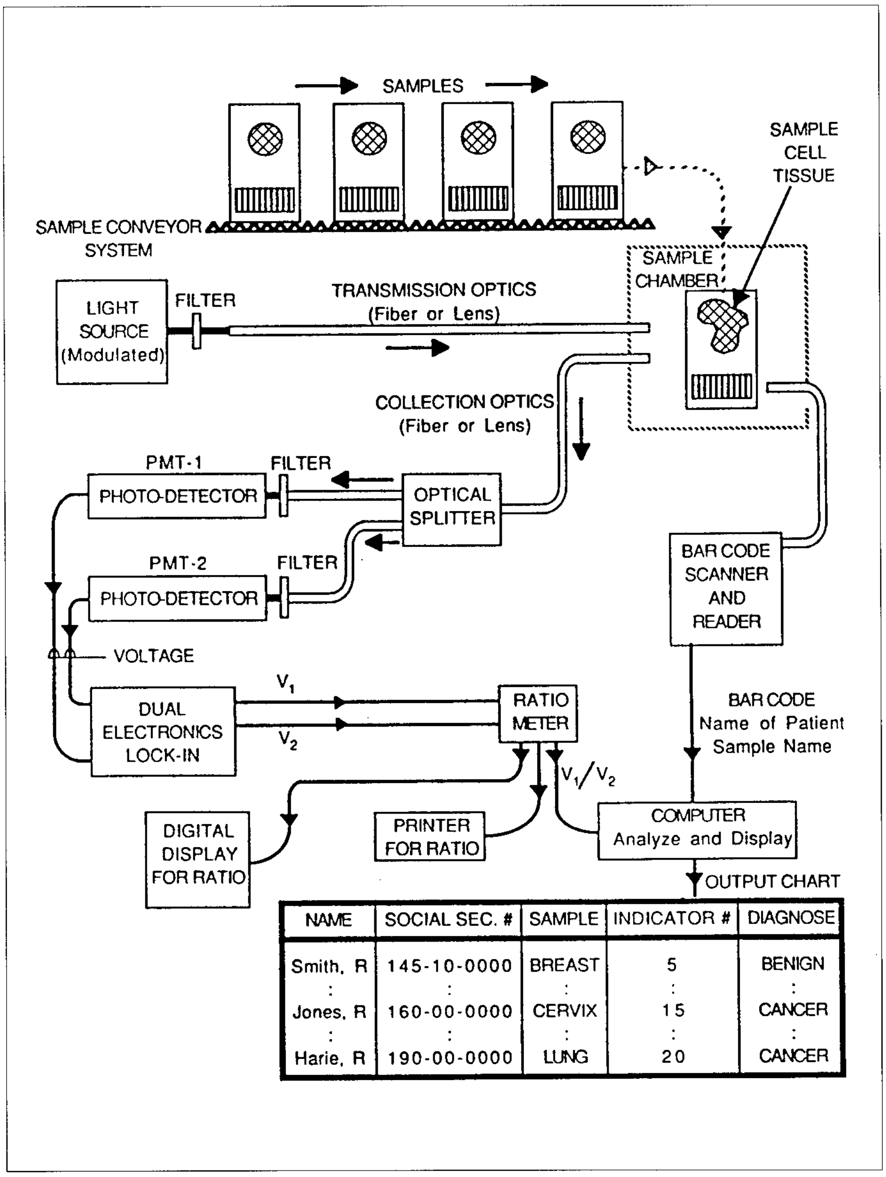
Program functions allow users to filter out noisy data, sharpen images, enhance image contrast, magnify or reduce images, perform numerical operations, display signals, and build a database of signals to compare to the image or signal under analysis. View can be operated on Sun and Silicon Graphics Iris workstations running the Window Systems with X11, and on UNIX workstations with X-Windows version 11. Users can also run View on the Macintosh II using the AUX system.

LLNL researchers are still writing and debugging View to increase its effectiveness. At present, the software is available to users free-of-charge; in exchange for use of View, LLNL receives feedback so that researchers can improve the software.



An image of a fly's head processed by "View," software developed at Lawrence Livermore National Laboratory to perform target tracking and non-destructive materials testing for SDI. View also has been used for applications in medicine, materials science, and telecommunications.

Cancer Diagnosis with Ultraviolet Light



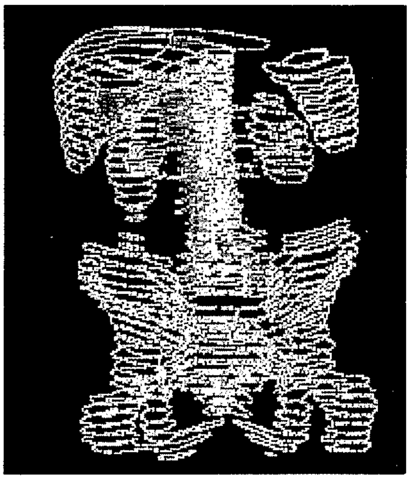
A schematic of the light biopsy system developed at City College of New York's (CCNY) Institute for Ultrafast Spectroscopy. CCNY developed the system through funding from the SDIO Medical Free-Electron Laser program, which Congress mandated in 1985 to develop spinoff applications of SDI's work in free-electron lasers.

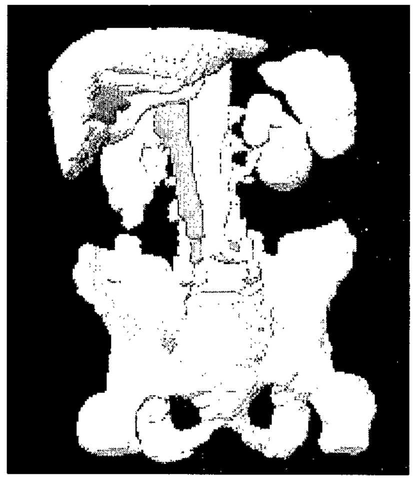
Laser light can now help distinguish between cancerous and normal tissue, thanks to research at the City College of New York's (CCNY's) Institute for Ultrafast Spectroscopy and Lasers (New York, NY). The CCNY technique, which employs optical spectroscopy (see sidebar), could soon allow doctors to diagnose some cancers without surgical biopsies or lengthy testing.

SDIO's Medical Free Electron Laser Program, which was established by law to promote medical applications of SDI's laser technology, initially funded this research. CCNY, which has patented the technique, is now working with Mediscience, Inc. to develop a biopsy instrument for clinical practice. The effort is currently in the prototype phase; the system must still secure Food and Drug Administration approval.

In optical spectroscopy, researchers illuminate a test sample with light waves and then measure resulting fluorescence from the sample to identify characteristics such as chemical composition, atomic energy levels, or molecular geometry. Thus, to distinguish between malignant and benign tissue, a 300 nanometer (nm) beam of light is directed onto a tissue sample suspected of being cancerous, and the intensity of the resulting fluorescence is measured. Research has shown that the ratio between fluorescence intensity at 340 nm and 440 nm has a consistent and significant difference in malignant and benign tissue. Studies have achieved greater than 90 percent accuracy in diagnosing malignant breast and gynecological tissue. The technique, however, can only differentiate between cancerous and non-cancerous tissue, not between different types of cancers.

Biomedical Imaging with Three-Dimensional Image Processing Software





The picture at the left shows a 3-D image traced from computerized tomography (CT) and magnetic resonance imaging (MRI) scans using previously available technology. The picture at the right shows how Kensal Consulting's Triakis traces the same image.

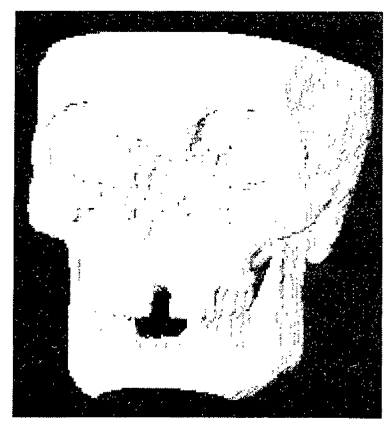
Software developed to detect ballistic missiles is now detecting cancer and other diseases. Under an SDI SBIR Phase I contract, Kensal Consulting (Tucson, AZ) developed software to detect multiple ballistic missile tracks from incomplete sensor data (see sidebar). Kensal has applied the software to the biomedical fields of radiology, pathology, cytology, and tissue morphology. In the last three applications, researchers and clinicians study tissue using cross sections on a slide under a microscope. Kensal's 3-D image processing would automate the process, allowing users to handle and analyze a larger volume of tissue samples.

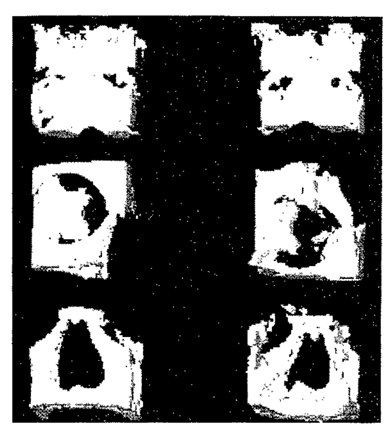
Kensal Consulting has developed and is marketing a Macintosh-based software package, Triakis 1.5, for these biomedical applications. The software accepts planar image data from various sources, computes the volumetric image, and projects color displays to suit user needs. Applications are currently limited to cell studies or research applications; potentially larger markets in diagnostic pathology have not yet been developed due to issues involving Food and Drug Administration approval. Studies of Triakis as a diagnostic tool, however, have shown that it can distinguish between large-celled and small-celled lymphomas with 97 percent accuracy, compared to 70 percent accuracy for expert pathologists.

Other possible applications for the software include teaching gross anatomy, examining integrated circuit surfaces, helping spacecraft avoid debris, and imaging cars as part of a "smart highway" transportation system.

Triakis 1.5, however, is currently limited by the speed of the microprocessor in the Macintosh. Kensal Consulting is seeking funding to build a co-processor board employing a custom Very Large-Scale Integrated (VLSI) chip that would greatly increase the software's computational speed.

During the SDI SBIR contract, Kensal Consulting developed software to emulate a computer architecture, designed and patented by Kensal, that detects ballistic missile tracks in 12 decibels of noise with a low false alarm rate. The Kensal computer architecture uses a mathematical procedure to convert — over several time frames — planar, scanned infrared image data into a dynamic 3-D "workspace." If this architecture were implemented in a VLSI microprocessor chip, millions of candidate target tracks could be checked every few milliseconds. The software emulating this new architecture also can perform 3-D analyses that, for example, can be applied to tomographic data (in effect, a "stack" of 2-D images) produced by radiographic, ultrasonic, or magnetic resonance imaging.





Triakis images produced from MRI and CT brain scans. Kensal Consulting developed Triakis under an SDI SBIR Phase I contract to produce software that can detect ballistic missiles using incomplete sensor data.

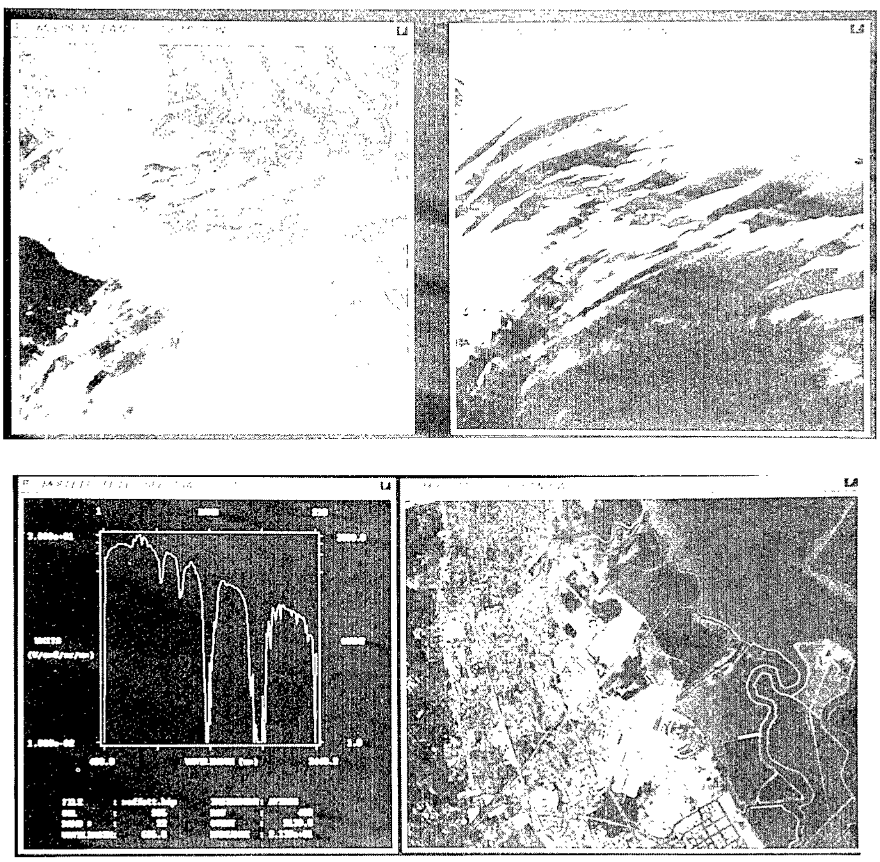
SDI SPINOFFS

Environment

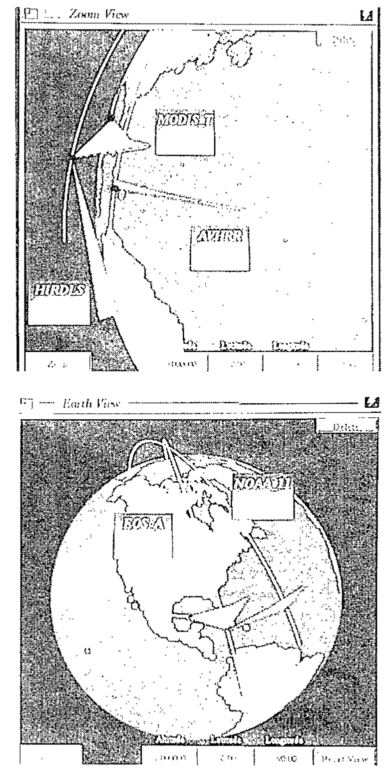
Environmental Modeling with Remote Sensing Tools

With geophysics models and computer technology developed for SDIO's Strategic Scene Generation Model (see sidebar), Photon Research Associates (PRA), Inc. (Arlington, VA) has assembled a set of modeling and analysis tools that can help researchers map the earth's resources, study the ocean, or monitor pollution sources. PRA's modeling tools allow remote sensing researchers to plan and manage spacecraft and sensor data collection, assess the quality and the utility of the collected data, exploit the data collected, and design and develop future sensor systems.

PRA has begun one contract with the NASA Lewis Research Center to enhance these tools to support passive microwave remote sensing applications. In addition, PRA is responding to another NASA procurement to support the Earth Observing System (EOS) Moderate Resolution Imaging Spectrometer sensor, has discussed using the tools to support the EOS Data Information System (EOS-DIS) with all the EOS-DIS contractor teams, and is pursuing applications for other NASA programs.



A simulation of cirrus cloud-cover over California. This simulation was produced by Photon Research Associates (PRA), Inc. using geophysics models and computer technology from the SDIO Strategic Scene Generation Model.

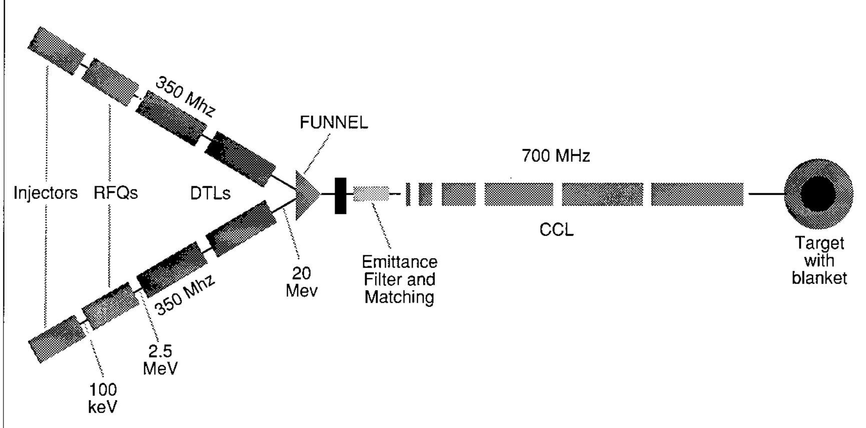


Satellite tracking using PRA's remote sensing and analysis tools. This function projects how much area a satellite (or system of satellites) will cover during a given orbit.

The Strategic Scene Generation Model (SSGM) will allow SDIO to test concepts and designs for detecting, tracking, and destroying ballistic missiles. The SSGM predicts which scenes SDI platforms will "see," accounting for missile and re-entry vehicle signatures, the effects of surface reflectance, cloud absorption or scattering, and interfering radiation (such as aurorea or nuclear detonation). The operator also can specify the wavelengths to be sensed from visible to intermediate infrared, and see how much area a satellite can cover.

With all this information, the SSGM then simulates an actual missile intercept, showing how a weapons system will locate, track, and destroy a ballistic missile. By providing a large database of physical phenomena, scenario parameters can be changed such as: earth backgrounds (tundra vs. desert), sky conditions (cloudy vs. clear), or launch scenarios (twelve targets only vs. three targets and forty decoys).

Cleaning Up Nuclear Waste



The system under which nuclear waste is converted to stable or short-lived radioactive elements.

The Los Alamos National Laboratory (Los Alamos, NM) has taken a concept for defense waste management that has been explored for decades, and improved it to the point that it is now an attractive option for destroying military wastes. The concept, called Accelerator Transmutation of Waste (ATW), will reduce the hazards of storing nuclear waste by converting long-lived radioactive waste into short-lived or non-radioactive material. ATE would not be possible without the large investments in high-current accelerator development made by SDI programs.

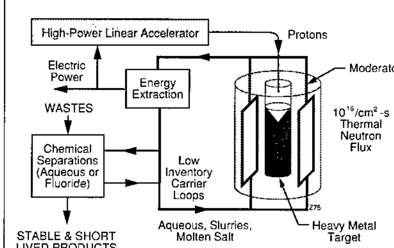
ATW converts (or transmutes) one element into another by altering the molecular structure of the substance. In ATW, an advanced, high-proton-current linear accelerator that was originally developed for SDI produces a high flux of low-energy neutrons. These neutrons, in turn, interact with nuclear waste and convert the waste into safer elements.

The ability to convert radioactive waste at a reasonable rate and with high efficiency sets the Los Alamos concept apart from other waste management projects. The intense outputs of neutrons from the accelerator allow efficient breakup of highly radioactive elements. This efficiency means that only limited amounts of radioactive material need to be in the reduction chamber at one time, and then only in a transient state as they are subjected to neutron bombardment; this reduced concentration at any given time improves safety. The Los Alamos concept, as a result, reduces concerns over nuclear safeguards, security, and environmental issues compared to conventional nuclear energy systems.

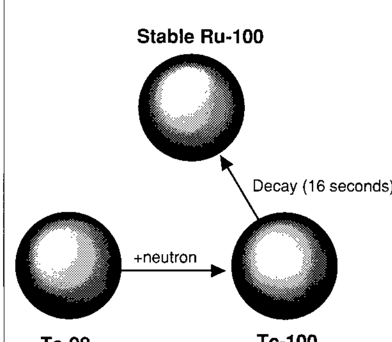
ATW would most likely first be applied to cleaning up waste left over from the Department of Energy's production of plutonium and other defense-related products. The ATW system also could be applied to commercial nuclear waste. Finally, because the ATW reaction actually generates energy, ATW could be integrated into a nuclear power plant that produces electrical energy with minimal amounts of long-lived, high-level radioactive waste.

In ATW, a liquid stream circulates nuclear waste into a chamber where it reacts with the accelerator-produced neutrons. A tank of heavy water — water made of deuterium, a naturally occurring hydrogen isotope with an extra neutron — is contained within the chamber. Because heavy water has an extra neutron, it slows down the neutron flux produced by the accelerator, thus giving the nuclear waste more time to react with the neutrons. During the reaction between nuclear waste and the neutron flux, some radioactive materials are converted into stable elements, while others are converted into elements with much shorter half-lives (often only a few minutes long).

In addition, because the reaction between the neutrons and the nuclear waste heats the liquid stream used to circulate the waste, the Los Alamos concept could generate electricity. In such a case, molten salts would circulate the waste, because they retain heat better than other liquids. Thus, molten salts would convert the heat generated in ATW into electricity more efficiently than other liquids.

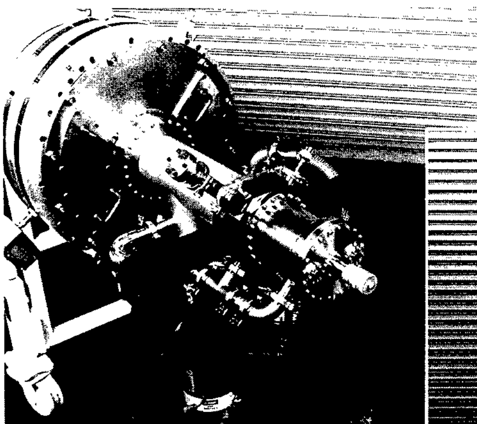


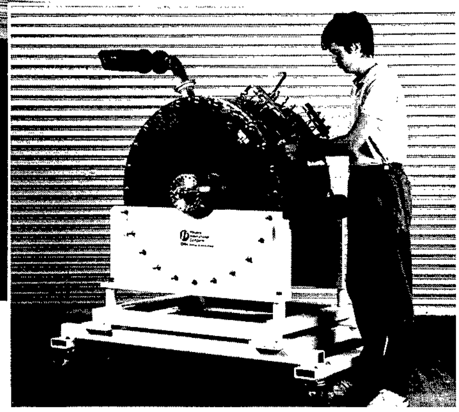
A proposed accelerator for transmuting nuclear waste. Such an accelerator would not be possible without SDI's investment in high-current accelerator technology.



One reaction in which nuclear waste is transmuted into a non-radioactive element. By capturing a neutron, technetium-99 becomes technetium-100, which in 16 seconds decays into the stable (not radioactive) element ruthenium-100.

Environmental Cleanup with High-Power Microwave Generators





High-power microwave generators developed by Physics International Corporation for the SDI IS&T program. These generators have potential applications in environmental cleanup, communications, power beaming, and fusion research.

Laboratory experiments have shown that microwaves destroy chlorofluorocarbons (CFCs). With this information, researchers have proposed that high-power microwave beams shot into the upper atmosphere could eliminate CFCs in the upper atmosphere. CFCs produce high levels of chlorine, which in turn serve as catalysts for the chemical reaction that destroys the ozone layer. Since the chlorine is a catalyst, the amount of this element in the upper atmosphere does not decrease as ozone is destroyed; instead, it remains in the atmosphere for about a century. Thus, the planned phaseout of CFCs will not reduce the amount of chlorine in the atmosphere for another hundred years.

To prove the idea will work, researchers need to investigate upper atmosphere chemistry in the presence of microwaves. If the research supports the theory, a series of microwave generators that Physics International Company (San Leandro, CA) developed with funding from the SDI Innovative Science and Technology (IS&T) program should produce the short-burst (one-billionth of a second) and high-power (one billion watts) microwaves needed to eliminate the huge inventory of CFCs in the upper atmosphere.

Other possible applications of Physics International's microwave generators include:

- **Electronic warfare**: The high-power microwaves produced by these generators could be used to jam enemy command, control, and communications devices at a greater distance than previously possible.

- **Radar**: Current radar technology offers peak power of about one megawatt. Physics International technology could increase peak power to 10 gigawatts. This increase in power would increase radar detection range tenfold. In addition, high-power microwaves could produce higher bandwidth radar signals, which improve resolution at extreme range, clutter rejection, penetration of the ground, and the probability of detecting hard-to-find targets.

- **Power beaming**: A solar-powered satellite could convert sunlight into stored energy, which microwave generators could then beam to earth. Also, earth-based or satellite-based microwave generators could be used to recharge satellites.

- **Plasma heating for nuclear fusion**: Several techniques using high-power microwaves are now being considered to heat magnetically confined plasma to 76 million° C, the breakdown temperature for thermonuclear fusion (the point at which fusion reactions generate as much energy as was used to start the reactions).

- **Laser pumping**: Although microwave generators have been used to pump lasers for some time, Physics International's high-power microwave generators should increase the power output of microwave-pumped lasers.

- **Radio frequency accelerators**: High-power microwaves could provide high-gradient electromagnetic fields for research-oriented particle accelerators.

- **Long-range communications and radar**: By shooting microwave beams into the atmosphere, microwave generators could ionize a small area of molecules in the ionosphere. The ionized particles could then be used as an artificial ionospheric mirror for bouncing low-frequency radar signals over the horizon.

Physics International developed its generators for SDI to power directed energy weapons. The company has sold four microwave generators in the U.S to companies involved in electronics testing, with several overseas companies interested in buying the devices as well.

Chlorofluorocarbon-free Refrigerators

As explained in the last write-up ("Environmental, Industrial Applications for High-Power Microwave Generators"), chlorofluorocarbons (CFCs) are the primary culprit for deterioration of the layer of ozone in the atmosphere that protects the earth from harmful ultraviolet radiation. Refrigerators and air conditioners are among the biggest users of CFCs, and the refrigeration industry is now looking for alternative coolants to replace CFCs.

Because the heat of the sun is greater in space than under earth's atmosphere, SDI's space-based platforms need advanced cooling systems. SDI sponsored the following three cooling systems for these space cooling needs. None of them use CFCs, and thus could help the refrigeration industry develop their own CFC-free systems.

Lightweight, High-Speed Compressor that Employs Magnetic Bearings


Two researchers from Mainstream Engineering Corporation assembling their high-speed compressor, which could replace compressors in any refrigerator or air conditioner on the market. Mainstream is developing the compressor under an SDI SBIR Phase II contract.

In a joint SDI SBIR Phase II project with SatCon Technology, Inc., Mainstream Engineering Corporation (Rockledge, FL) is developing a high-speed compressor that uses magnetic bearings. In the project, Mainstream Engineering is responsible for the compressor's overall design, while SatCon is contributing its magnetic bearing technology (see page 54) to build the compressor motor. The compressor will initially drive heat pumps used to cool spacecraft.

While compressor-driven heat pumps cool spacecraft more efficiently than heat pipes, heat pipes have traditionally been more reliable. By employing non-contact, magnetic bearings, the Mainstream compressor rivals heat pipes in reliability while maintaining the efficiency of heat pumps.

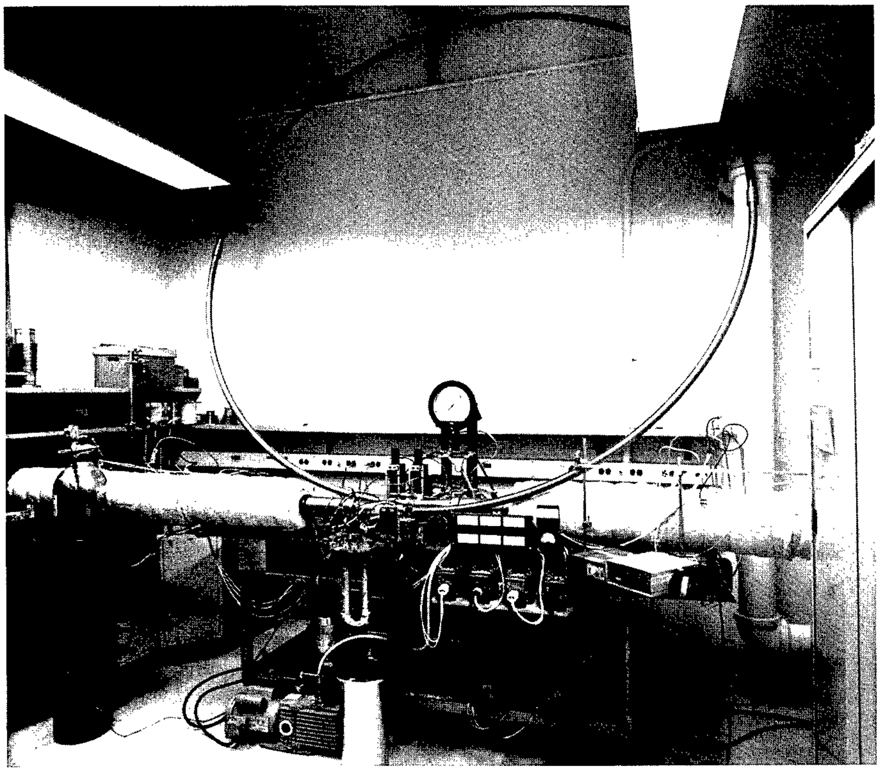
Automobile air conditioning systems furnish the compressor's nearest-term commercial market. The energy efficient design of the compressor would allow car makers to move the air conditioner from the engine drivetrain to an electrically driven system, which would increase energy efficiency and make maintenance easier. An air conditioner that does not take power from the drivetrain also could help designers develop electric vehicles that compete with the accelerating power of gas-driven cars.

Magnetic bearings, described on page 54, have been used with great success in large industrial centrifugal compressors but, until recent advances in microelectronics, have not been used in smaller compressors. In magnetic bearings, moving parts "float" in a magnetic field without contact to nearly eliminate friction and wear. As a result, the operating life of the compressor is no longer limited by wear, but instead by the reliability of the electronics.

Magnetic bearings also improve efficiency. Conventional compressors cannot operate at high speeds because of friction-generated heat at high speeds. This heat, in turn, breaks down the lubricant. Magnetic bearings do not use lubricants; and, as a result, this compressor can operate at higher speeds. Higher speed operation makes the compressor more efficient, meaning a smaller, lighter compressor can do more work.

The Mainstream design also incorporates modern materials to reduce weight, inverts the compressor's impellers to improve cooling efficiency and eliminate the liquid accumulator, uses the magnetic bearings to correct for minute out-of-balance forces inherent in the rotating structure, and uses R-134a as a refrigerant to replace chlorofluorocarbons.

The "Coolahoop:" A Cyrocooler Without Moving Parts



The Coolahoop. Researchers at Los Alamos National Laboratory and the National Institute of Standards and Technology developed the Coolahoop to cool SDI's space-based infrared sensors. Because it has no moving parts, it is ideal for maintenance-free cooling in remote locations.

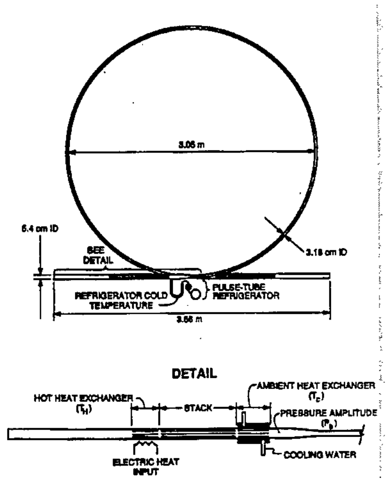
The Coolahoop, designed by Los Alamos National Laboratory (Los Alamos, NM) and the National Institute of Standards and Technology (Gaithersburg, MD) to cool SDI infrared sensors on space platforms, may lead to maintenance-free cooling for operations that occur in remote locations, such as natural gas production, climate and resource monitoring, and livestock breeding.

The Coolahoop's unique design (see sidebar) in which sound waves replace mechanical compressors to compress the refrigerant, distinguishes it from conventional cryocoolers. Because it does not contain exotic materials, have pistons or cylinder walls, or require close-tolerance fabrication techniques, it will likely cost one-fifth to one-tenth less to manufacture than conventional cryocoolers.

The first prototype of the Coolahoop reached a low temperature of -184° C (89 K), although later versions could reach even lower temperatures. Thus, besides cooling in remote locations, the Coolahoop could be used to cool superconducting computer components and components of conventional computers. Also, it could serve as a cryo-pump to create the vacuums necessary for computer chip lithography. Finally, it could be incorporated into components of Magnetic Resonance Imaging medical equipment, which need to be kept at low temperatures.

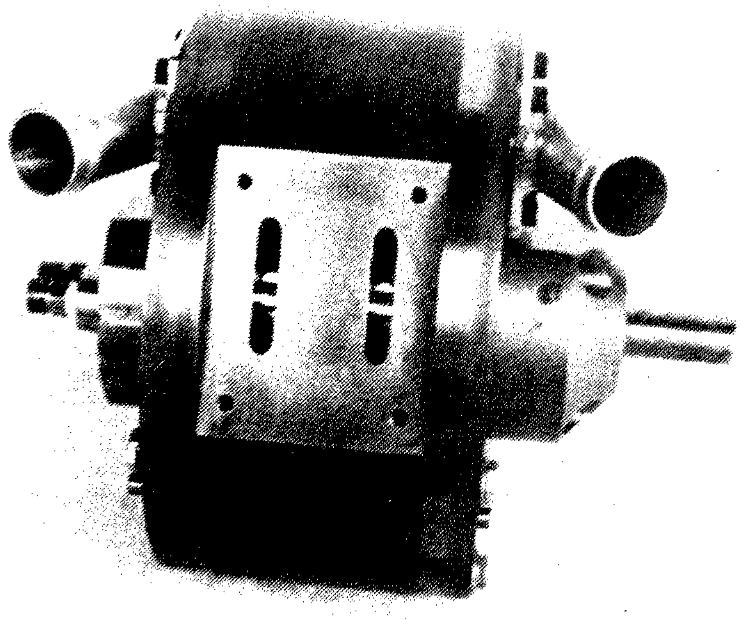
The SDIO Technologies Market Assessment Project, a technology transfer demonstration project directed by the SDIO Office of Technology Applications and the State of New Mexico (see page 2 in the Introduction), is currently evaluating the commercialization potential of this technology. The Coolahoop, which was patented in September 1990, is available for licensing.

The Coolahoop is a simple device comprised of brass, copper, and stainless steel tubes and heat exchangers that contain helium gas. It uses a thermoacoustic engine — a device in which acoustic resonance converts heat into oscillatory pressure —to pressurize and depressurize helium contained in a pulse tube refrigerator. By replacing mechanical compressors with an acoustic wave, the thermoacoustic engine eliminates moving parts. This, in turn, increases reliability and system lifetime while decreasing maintenance requirements.



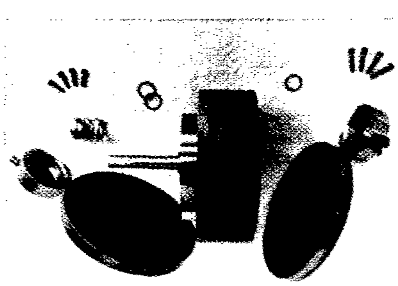
A schematic of the Coolahoop. Shown in the upper diagram is the large, circular resonator, where acoustic waves convert heat to oscillatory pressure. The pulse tube refrigerator, where heat is exchanged, is shown in detail below. Each Coolahoop has two such refrigerators.

Rotary Vane Compressor



The rotary vane compressor developed by Applied Technology under an SDI SBIR contract. The rotary vane compressor provides low-cost cooling without using ozone-depleting chlorofluorocarbons.

Applied Technology (Orlando, FL), with funding from the SDI SBIR program, designed a compressor for a spacecraft heat rejection system that could replace compressors now being used in air conditioners and refrigeration systems. This rotary vane compressor can use several different refrigerants to reduce the use of harmful CFCs. The rotary vane compressor also is more efficient than other compressors and requires less maintenance because its design minimizes friction losses and gas leaks. Other benefits of the rotary vane compressor include low cost, variable speed, low discharge temperature, and direct drive.

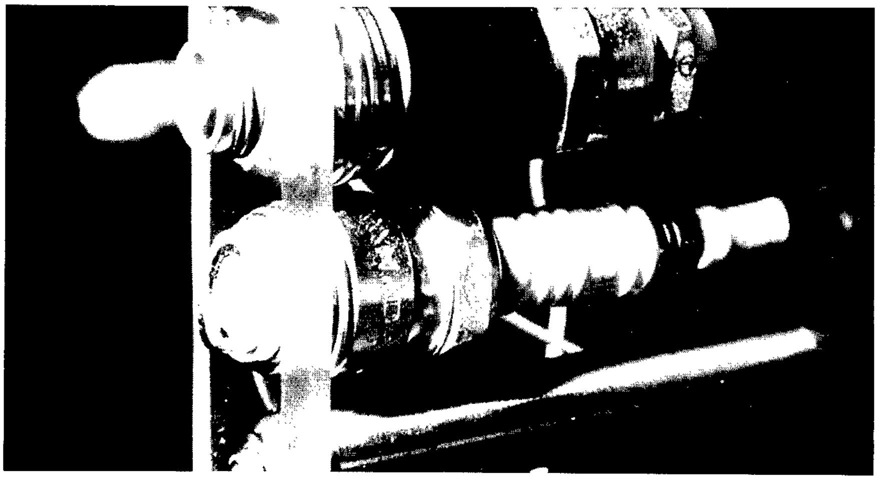


So far, applications for the rotary vane compressor have centered around special applications, mostly for the military. For example, the compressor can compress gases in propulsion systems, as in an amphibious propulsion system Applied Technology is building for the Navy. In this propulsion system, the mix of diesel fuel and air must be compressed to a pressure of 225 pounds per square inch. To do this the compressor must be driven by an 800 horsepower engine. Standard compressors would have to be the size of half a garage to fulfill this task, while a rotary vane compressor of comparable performance could fit under a car's hood.

SDI SPINOFFS

Energy

Saving Gas with Railgun Sparkplugs



A comparison of a railplug (top) and a conventional sparkplug (bottom). As shown here, the railplug creates a larger "spark," which makes cars easier to start and allows gas in the combustion chamber to burn more completely. The railplugs, developed by University of Texas researchers while investigating railguns for SDI, could save 10 billion gallons of gasoline per year if they replaced conventional sparkplugs in every car in the U.S.

Miniaturized railgun technology could save 10 billion gallons of gasoline a year and reduce pollution caused by car emissions if every car in the United States used new "railplugs" developed at the University of Texas at Austin. The railplug, which replaces conventional sparkplugs, spun off from research on electromagnetic railguns for SDI directed energy weapons.

Railplugs ignite over 200 times more plasma mass (ionized gas) than conventional sparkplugs, and send the plasma into the piston cylinder at a high velocity. By igniting more plasma, railplugs burn fuel more completely than sparkplugs, while the high velocity moves the ignition process away from the relatively cold combustion chamber walls. In engines using sparkplugs, the cold chamber walls often extinguish a flame during its initial stage. With these two advantages over sparkplugs, railplugs make cars easier to start, especially in cold weather.

In addition, railplugs are better suited to engines that burn lean fuel/air mixtures (low in fuel, high in air). Lean-burning engines increase fuel efficiency and reduce exhaust pollutants. Sparkplugs do not easily ignite lean fuel mixtures; and, even if ignited, the diluted flame travels so slowly that it hinders thermal efficiency. Railplugs rapidly burn lean mixtures, resulting in a 10 to 25 percent savings in fuel.

Railplugs also are more versatile than sparkplugs, and work in the following engines:

- **Indirect injection diesels.** Conventional diesel engines use glowplugs to ignite diesel fuel; however, glowplugs do not ignite diesel fuel at cold temperatures. To make cold-weather starts, standard diesels must increase the compression ratio beyond the optimum level. Railplugs allow ignition in cold weather at optimal compression ratios, increasing fuel efficiency, engine durability, and emission quality.

- **Jet engines.** By replacing conventional ignitors, railplugs would make relighting jet engines at high altitudes easier.

- **Dual-fuel engines.** Ordinary dual-fuel engines, such as those that run on either gasoline or alcohol, require two types of sparkplugs — one for burning gasoline and one for burning alcohol. Railplugs, however, can ignite both.

The simplest railgun consists of two parallel electrodes or "rails." When a high voltage is applied across the rails, an arc jumps across them. The current flowing down one rail, across the arc, and back up the other rail produces an electromagnetic force, known as a Lorentz force, which rapidly accelerates the arc down the rails. In a railgun, a projectile is forced ahead of the rapidly moving plasma arc at greater velocities than conventional explosive-driven guns.

Railguns typically produce plasma at temperatures of 10,000 to 50,000° C, and with plasma velocities that exceed the escape velocity from the solar system — over 20,000 meters per second. The rails can be arranged in coaxial, diverging, converging, or helical configurations to produce a wide variety of plasma jet flow patterns. The plasma jet that leaves the railgun contains an enormous amount of thermal and kinetic energy, and helical designs can even form a swirl in the plasma jet.

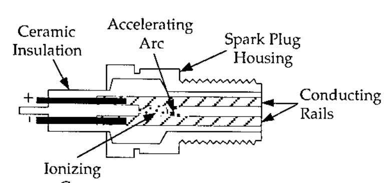
When miniaturized as a railplug, the high-velocity plasma jet provides the following benefits over sparkplugs. The plasma jet:

- Produces a line source of ignition rather than a conventional point source of ignition. This causes a greater mass of fuel to be burned early in the combustion process.

- Acts as a distributed ignition source so that the flame travels a shorter distance in the combustion chamber before consuming the entire fuel/air mixture. Because the engine consumes the entire mixture more rapidly, the railplug increases thermal efficiency and improves fuel economy.

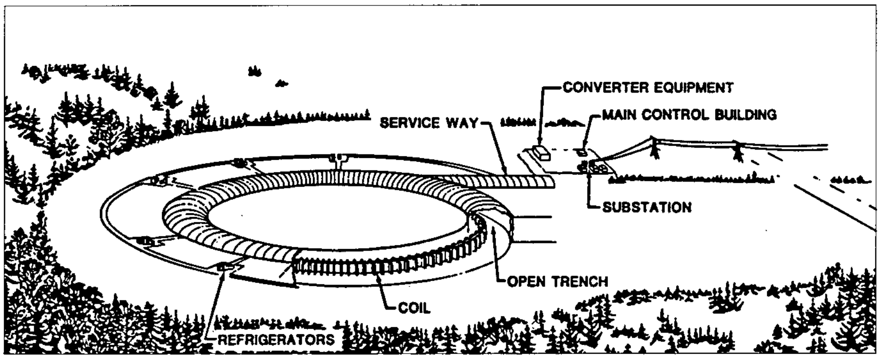
- Minimizes the variation from one cycle to the next—particularly at idle speeds — and decreases the tendency for the engine to knock. Conventional engines increase the idle speed to overcome cyclic variability, which reduces fuel economy. The railplug, however, allows lower idling speed, which saves gas.

- Travels so fast (Mach 3) that it induces shock wave turbulence in the combustion chamber. This further increases the rate of combustion, thermal efficiency, and fuel economy. The railplug's higher thermal efficiency also leads to greater power and torque.



A schematic of the railplug. Current travels from the negative rail, across the ionized gas, and back up the positive rail to produce an electromagnetic force that shoots the ionized gas out the plug.

Storing Electricity for Utilities



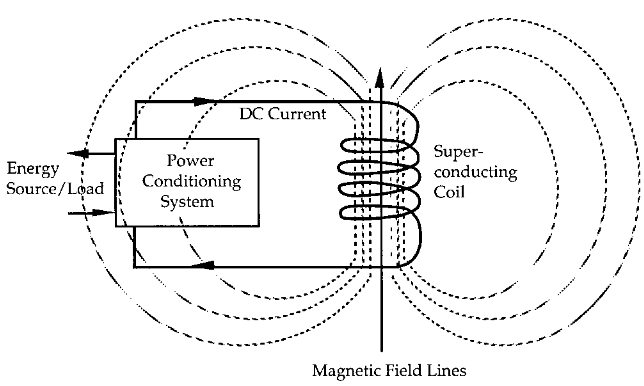
A schematic of a superconducting magnetic energy storage (SMES) system built within a circular trench. The SMES, developed for SDI to rapidly energize a free-electron laser, can store electricity for electric utilities and other applications.

In the event of a nuclear attack, SDI's free-electron laser would need to rapidly energize to produce a beam powerful enough to destroy an enemy warhead. SDI started to develop a superconducting magnetic energy storage (SMES) system, which uses coils of superconducting wires to store electricity in magnetic fields (see sidebar), to provide the free-electron laser with this capability. Because the SMES stores and rapidly discharges electrical current, electric utility companies also want to develop SMES technology.

The SMES could tie into the power grid to help electric utilities handle peak output demands more efficiently. A utility could charge the SMES when there's little demand for power (at night), and use it when needed during the day. Utilities would therefore not have to build new power plants just to handle peak load. A SMES also could serve as a back-up during system failure.

A SMES unit can balance changes in power output almost instantaneously, allowing generating units to operate at constant output. By doing so, the SMES could allow generating units to operate at their most efficient levels. The SMES would thereby increase efficiency and system lifetime, while reducing maintenance and downtime.

In addition, because magnetic fields can align or orient materials, the magnetic fields produced by a SMES test device can be used to study and fabricate special materials. The magnetic fields also could be used for physics experiments, biology experiments, or to study the effect of magnetic fields on electrical equipment.



Magnetic fields produced by the superconducting coils in a SMES unit. These magnetic fields store electrical energy in the SMES.

The SMES stores electrical energy in a magnetic field through the following mechanisms:

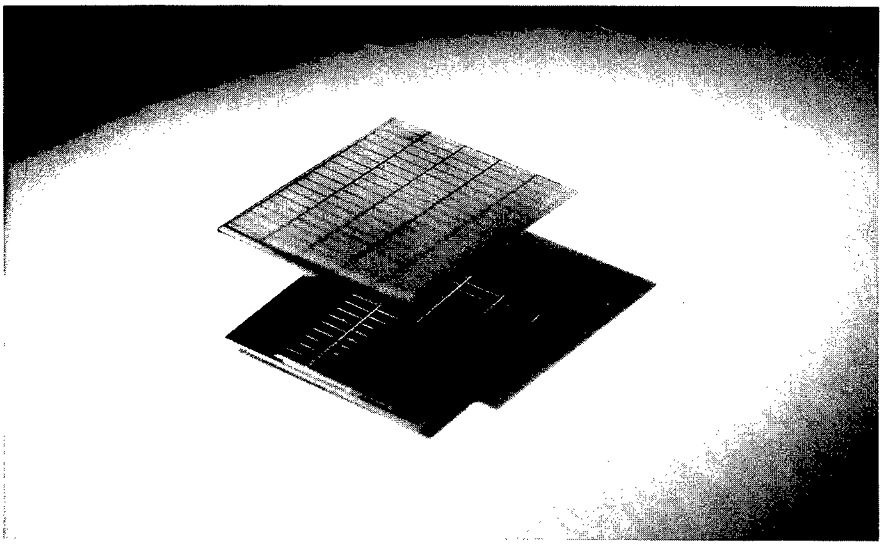
- Electric current passing through coils of wires produces magnetic fields, which store electromagnetic energy within the system. The coils resemble the solenoid coil in a car, only the SMES coil may be the size of a football field (see diagram).
- The coils in a SMES are made of superconducting materials. Superconductors are materials that under certain conditions (usually extremely low temperatures) conduct electricity with no resistance. Thus, because electrical resistance does not dissipate energy, SMES coils can store electricity efficiently.

To store energy, AC current from the electric utility grid is converted to DC current using solid state power conditioning. (In a superconducting coil, one must have DC current for no resistance losses; AC current produces some losses.) To discharge energy from the SMES unit, the current is fed back to the power conditioning components, which converts DC back to AC power.

The SMES can store and discharge electrical power at efficiencies up to 95 percent, with very fast response times — in the millisecond range. The test model that has been proposed to validate the large-scale SMES will store 20 megawatt hours (MWh) of energy, and discharge it at a rate of 10 to 400 MW. A large facility might store 5,000 MWh, and provide it at a rate of over a gigawatt — the same power output as a nuclear power plant provides over five hours.

Construction of a SMES will have several technical challenges. To become a superconductor, the solenoidal coil must be cooled to -271.2° C (1.8 K) with superfluid liquid helium and surrounded by a vacuum. Also, the energized SMES coil exerts a large Lorentz force (the force exerted by current passing through a magnetic field) in the outward radial direction. For large coils, the least expensive way to support this load is to locate the coil in a circular trench, the walls of which resist the radial Lorentz force. For the test model, the trench will be approximately 10 meters deep, 5 meters wide, and 130 meters in diameter.

Harnessing the Sun's Energy with Efficient Solar Cells



A tandem solar cell array developed by AstroPower, Inc. under SDI SBIR contracts. This array, with an aluminum gallium arsenide top cell and a silicon bottom cell, should increase energy conversion efficiency to 27 percent (conventional solar cell arrays typically have efficiencies of about 20 percent).

SDI SBIR seed capital funding has helped AstroPower, Inc. (Newark, DE) develop solar cells and solar energy systems now on the market, and begin research and development on the next generation of ultra-thin, radiation-hard, high-efficiency solar cells. Three examples of these solar cells are:

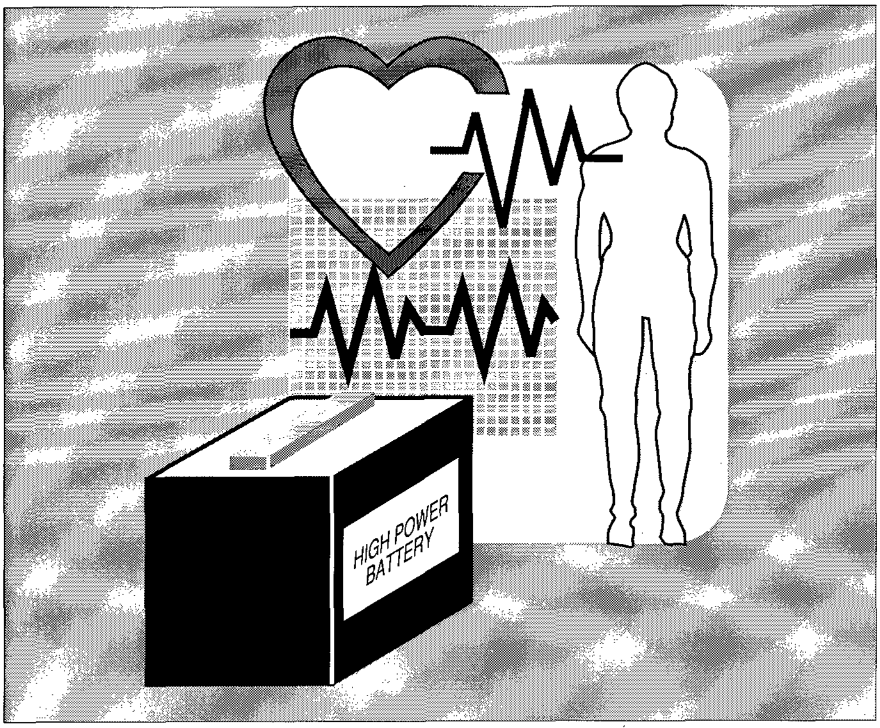
- **Tandem Solar Cells using Aluminum Gallium Arsenide**: The tandem cell approach is expected to increase efficiency of space-based solar power systems to 27 percent, by using an aluminum gallium arsenide (AlGaAs) top solar cell mechanically connected to a silicon concentrator bottom solar cell. The AlGaAs in this tandem cell structure increases system efficiency by converting light above the red spectrum to electrical energy. This technology also can be applied to optoelectronic devices, and AstroPower, Inc. has used it to create ultra-bright light emitting diodes (see page 28). Another potential application is for low-power, long-life batteries that incorporate a stable electron source, phosphorescent materials, and an AlGaAs-based solar cell.

- **Electrical Contacts that Can Survive High Temperatures**: These contacts are used to improve the survivability of solar cells in high temperatures (possibly during the manufacturing process). The high-temperature contacts are created by depositing an intermediate metal semiconductor layer between, for example, the silicon of a silicon solar cell and the high-temperature metal alloy electrical contacts. In addition to direct application in manufacturing III-IV (such as gallium arsenide) or silicon-based solar cells, the high-temperature contacts can be used in silicon diodes, silicon integrated circuits, or III-IV-based optoelectronics.

- **Electrostatic Bonding of Glass Superstrates to Solar Cells**: Through electrostatic bonding, a thin glass superstrate can be placed over a silicon solar cell, without using any adhesives. The rigid and comparatively strong superstrate provides protection from radiation, and allows the active silicon layer to be very thin, such that the entire assembly is less than 25 microns thick. While the solar cells are designed for space-based applications, the electrostatic bonding process can be used to manufacture a wide variety of optoelectronic devices.

AstroPower expects commercial sales of these products to begin in the early to mid 1990s, with sales of its solar cell devices to reach $28 million by 1995.

Powering Computers and Cars with Compact, High-Power Batteries



Paper-thin rechargeable batteries developed by the Enyon Corporation during SDI SBIR contracts could be used for automotive electrical systems, cardiac pacemakers, and other critical continuous energy needs. The batteries also could provide pulsed power for accelerators, robots, and hand tools.

Paper-thin rechargeable bipolar batteries may replace conventional parallel plate lead-acid batteries or bobbin-type batteries since research indicates that they can provide more power and energy from a smaller, lighter battery.

Under SDI SBIR contracts, Enyon Corporation (Provo, UT) researched the bipolar battery technology to deliver short, high-power pulses of electricity for advanced railgun and laser applications. The recharging qualities of bipolar lead-acid battery cells have been bench-tested over one million rapid charge-discharge cycles. If bench test performance carries over to practice, Enyon batteries should last for over four years of heavy duty cycling, which far surpasses the life of conventional batteries.

As a result, these high-power bipolar batteries could replace capacitors in pulse accelerators, robots, and hand tools, as well as provide backup power for computers. Other applications include high-voltage automobile and aircraft electrical systems, portable battery packs for soldiers, light-weight batteries for laptop computers, built-in emergency system power sources, and other critical continuous energy needs.

Enyon is discussing commercialization possibilities with the Electric Power Research Institute and General Motors. In the near-term, Enyon's efforts will emphasize lead-acid battery commercialization and zinc-nickel cell research, while lithium-based battery systems are a long-term goal.

Bipolar batteries are made by stacking thin sheets of an electrically conducting bipolar plate, active material, and ionically conducting separator, then sealing the edges and filling the assembly with an electrolyte. Sheet thickness can be less than 0.02 cm, resulting in batteries as thin as 0.04 cm. Bipolar battery technology originated in the 1870s, but has become commercially viable only with recent advances in materials and manufacturing techniques.

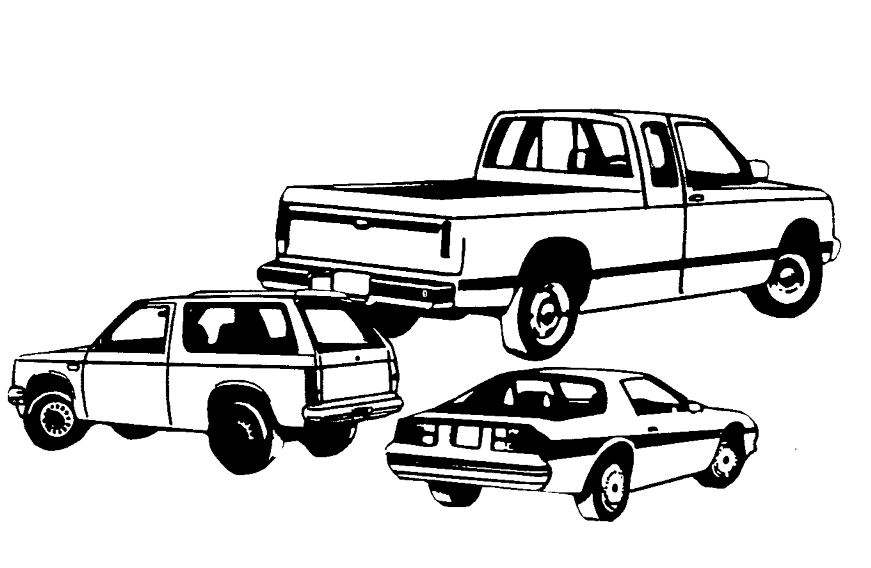
Battery materials determine battery power and energy densities more than anything else. Zinc-nickel and lithium-based systems provide high energy densities, but only modest power. Lead-acid systems, in turn, provide very high power, but only moderate energy densities. For example, energy densities are typically 20 watt-hours per kilogram (Wh/kg) in conventional mass-produced lead-acid batteries, and about 40 Wh/kg in bipolar lead-acid batteries, while they should approach 120 Wh/kg in zinc-nickel systems, and 400 Wh/kg in lithium-based systems. In addition, conventional lead-acid batteries have a power density of 0.35 kilowatts per kilogram (kW/kg), one-fourth that of bipolar lead-acid batteries.

Performance testing of these bipolar cells enables Enyon to project full-scale battery power levels of 500 kW/kg for a one millisecond discharge down to 2 kW/kg for a five-second discharge. Enyon researchers estimate that, in the near future, they can produce a multi-cell battery with dimensions of 17.8 cm square by 1.78 cm thick, and weighing 2.25 kg, that delivers 70 amps at 45 volts. This represents a power density of 1.4 kW/kg and an energy density of 40 Wh/kg.

SDI SPINOFFS

Consumer Products

Brighter Brake Lights from Light Emitting Diodes



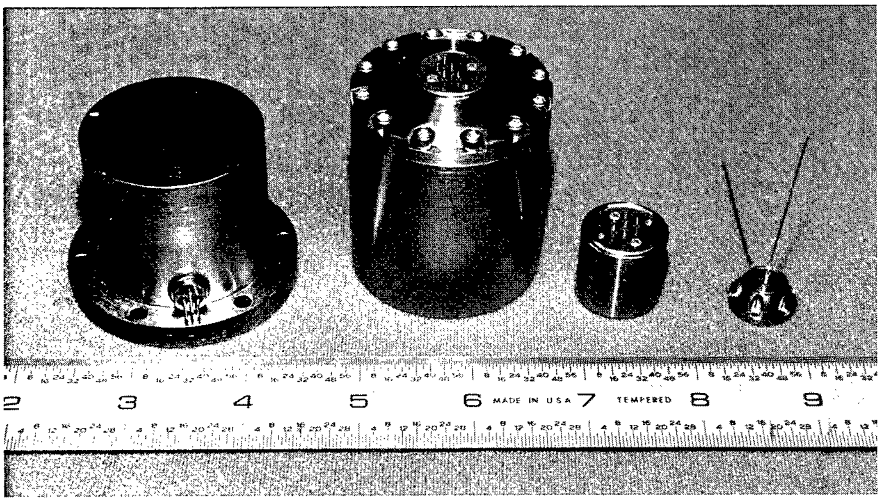
Brake lights using ultra-bright light emitting diodes that AstroPower, Inc. is developing under an SDI SBIR contract would allow the driver of a following car to recognize that your car is braking one-fifth of a second sooner. By reducing reaction time one-fifth of a second, a car travelling 60 mph would stop 18 feet sooner.

Soon automobile drivers may have an extra 18 feet of braking space, thanks to technology being developed by AstroPower, Inc. (Newark, DE). Under SDI SBIR contracts, AstroPower researchers are developing ultra-bright light emitting diodes (LEDs) that can allow drivers to see brake lights flash 200 milliseconds (ms) sooner. Cutting reaction time 200 ms will allow drivers in following cars to brake 18 feet sooner when travelling 60 mph.

AstroPower designed the ultra-bright red LEDs while researching a proprietary liquid phase electro-epitaxy (LPEE) process, which uses an electric current to control the epitaxial growth of semiconductor films from liquid metal solutions. The proprietary AstroPower LPEE process is designed to increase the optical intensity of surface light emission by reducing optical absorption in the semiconductor substrate. Surface emitting lasers made using LPEE can be used in laser communications, data linking, optical computing, and laser pumping. The brighter red LEDs also could be used in avionics and vehicular instrumentation.

One of the first small businesses to obtain a National Institutes of Standards and Technology (NIST) Advanced Technology Program award, AstroPower will develop a commercial-scale fabrication facility for these ultra-bright LEDs. Presently, the worldwide LED market is dominated by Japanese firms, and should be worth about $600 million in the next few years.

Car Safety Improved with Motion Sensors



Magnetohydrodynamic sensors, developed by Applied Technology Associates (ATA) for SDI pointing and tracking experiments. These sensors feature a small, reliable construction that has been tested to withstand forces 1,200 times that of gravity.

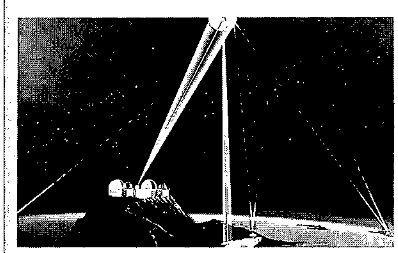
The Department of Transportation is improving car safety with magnetohydrodynamic (MHD) sensors that were developed for SDI pointing and tracking experiments (see sidebar). Because MHD sensors are smaller, lighter, less expensive, and more energy-efficient than sensors of comparable performance, the Department of Transportation has put them in crash dummies to study the human body's response to collisions. Data from these tests will allow automobile designers to develop safer passenger compartments.

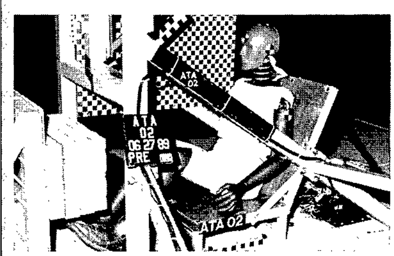
Applied Technology Associates (ATA), Inc. (Albuquerque, NM), which developed MHD motion sensors for SDI, has sold over 200 of the sensors worldwide and patented two versions of the MHD sensors. In addition, ATA has integrated several models of the MHD sensor into an active control loop for hand-held and platform-mounted cameras. The system eliminates jitter, allowing blur-free pictures even in high-vibration environments such as helicopters and tanks. MHD sensors also have been used to measure the rotation of cannon projectiles while they are fired. The peak angular rate provides an estimate of the muzzle velocity, which can be used to set electronically timed fuzes.

Other applications for the sensors include measuring attitude (orientation relative to a fixed axis) in smart bombs, replacing gyroscopes for navigation and flight control, serving in anti-lock braking systems, and providing active ride control in cars and other vehicles. In manufacturing applications, the sensors could detect bearing failure in rotational equipment such as engines, drivetrains, compressors, conveyors, and generators. Also, because the sensors can make accurate measurements of angular deflections, they could measure how much and how often structures bend, thus testing the structural design of new aircraft and automobiles.

Magnetohydrodynamic sensors, which use the interaction between a fluid and a magnetic field to measure angular motion, operate with excellent precision in diverse environments. These solid-state, hermetically sealed sensors are as small as a dime and weigh just 7 grams. Analytical predictions have shown the sensors could withstand forces 50,000 times that of gravity, and they have been tested under forces 1,200 times that of gravity. Other performance characteristics include:

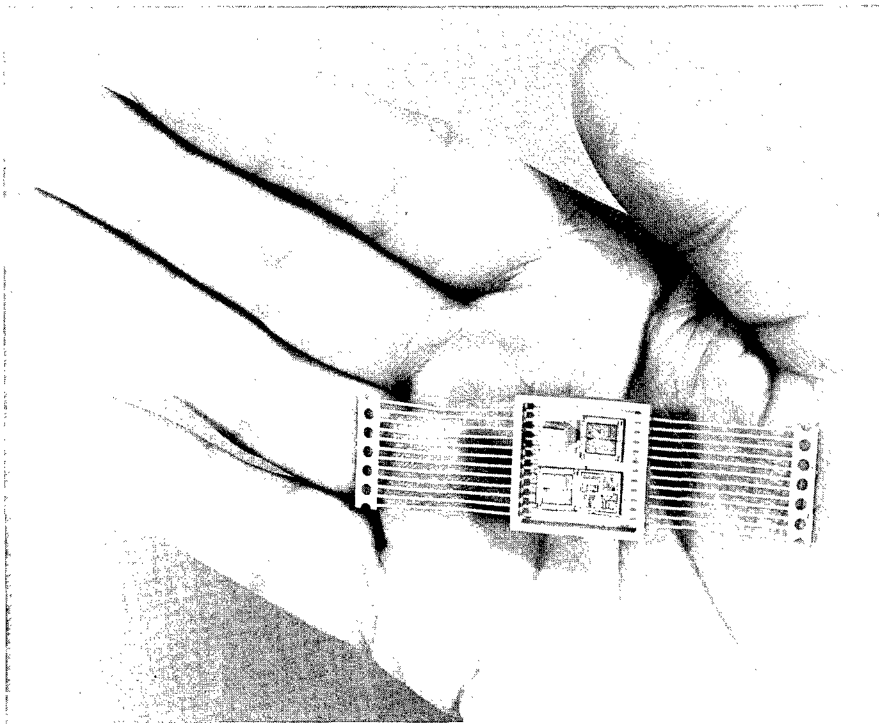
- A dynamic range exceeding 100 decibels
- Low noise, better than 0.1 microradian root mean square in some models
- Broad angular rate measurement bandwidth up to 1,000 Hz
- Inertial rate measurement over more than three frequency decades
- High angular rate sensitivity
- Low cross-axis angular and linear acceleration sensitivity
- Integral thick-film hybrid electronics for maximum signal-to-noise ratio.



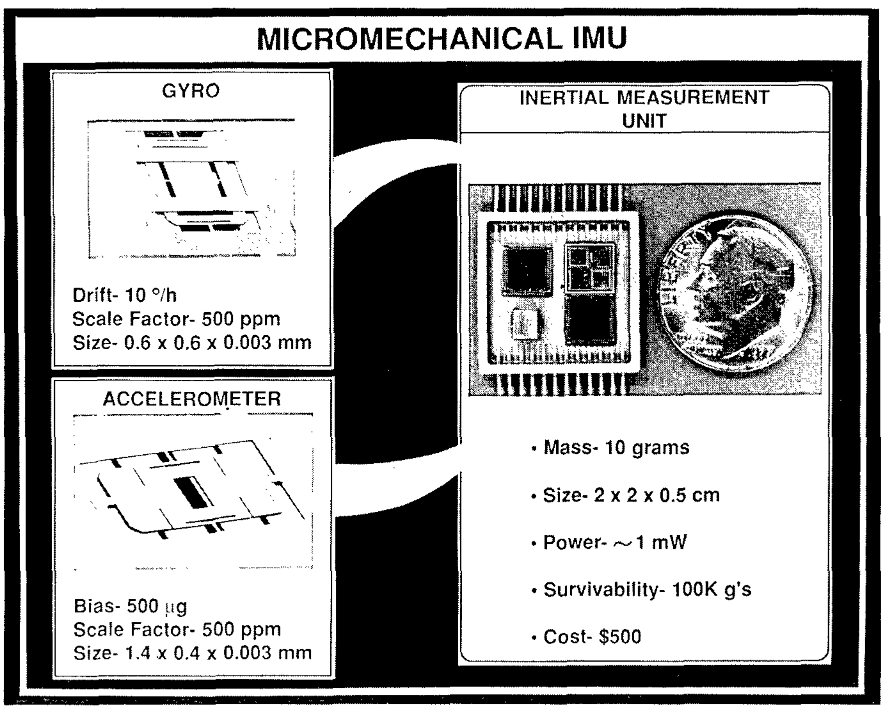


Applications of ATA's angular motion sensors: pointing and tracking experiments for SDI (top) and automotive safety research (below). In the latter application, the sensors are strategically placed in the crash dummy's head to measure head rotation during a car crash. This information will allow automobile designers to develop safer passenger compartments.

Miniature Sensors for Cars, Airplanes, and Toys



A prototype micromechanical inertial measurement unit (IMU). The unit, which the Charles Stark Draper Laboratory developed under an SDI IS&T contract, has applications in the automotive, aviation, medical, and entertainment industries.

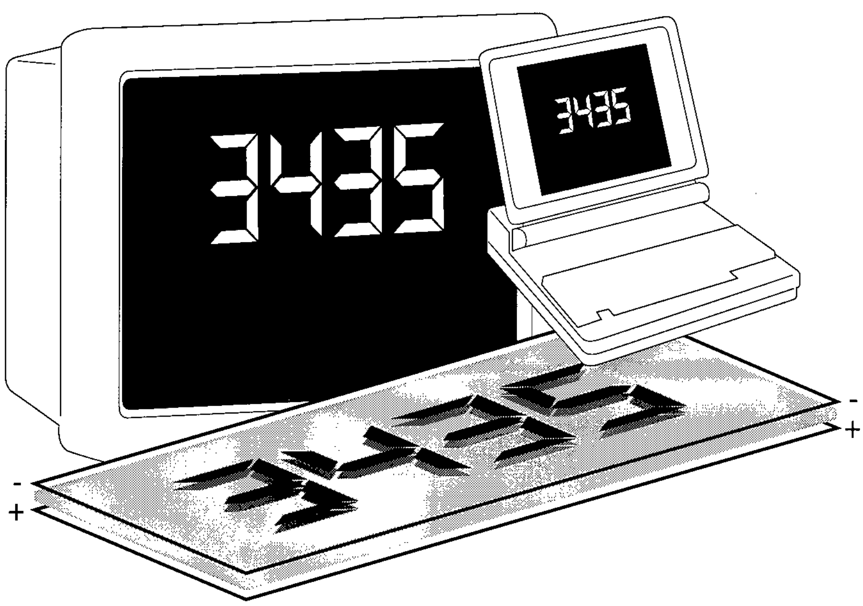


The Charles Stark Draper Laboratory's micromechanical IMU combines an accelerometer and a gyroscope into a single, low-cost package.

Because of their small size, light weight, and low cost, miniature sensors that measure changes in speed and orientation have potential automotive applications such as detecting skids for anti-lock brakes, measuring deceleration for airbags, and compensating for bumps to provide smoother car rides. Under an SDI IS&T contract, researchers at the Charles Stark Draper Laboratory (Cambridge, MA) developed these sensors for satellite navigation systems. The sensors combine accelerometers and gyroscopes on a single silicon chip the size of your fingernail (2x2x0.05 cm). In addition, they require less than a milliwatt of power. Other potential applications for the sensors include navigation systems, scene-stabilized camcorders, general aviation, medical electronics, and children's toys.

The sensors are made by chemically etching a wafer of single-crystal silicon; in this process, 4,000 guidance systems can be produced at one time from a single 4-inch square wafer. The gyroscope is expected to perform with drift uncertainty of about 10 degrees an hour, which is acceptable for short term navigation. The accelerometer, with seconds of integration time, is expected to measure acceleration to within 0.0005 times that of gravity.

High-Definition Television Screens from Ferroelectric Liquid Crystals



One application for ferroelectric liquid crystals (FLCs), developed by Displaytech, Inc. during SDI SBIR contracts, is in displays for computer monitors and high-definition television sets. FLCs, sandwiched within glass plates, are operated between crossed polarizers.

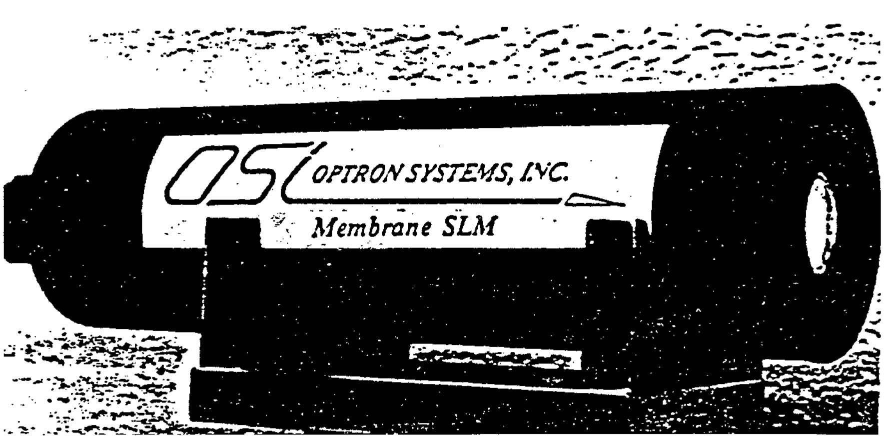
Ferroelectric liquid crystals (FLCs), which Displaytech, Inc. (Boulder, CO) developed during SDI SBIR contracts, are a faster switching (1 to 10 microsecond) version of the liquid crystals found in watch and calculator displays (see sidebar). SDI funded development of FLCs to serve as high-speed optical interconnects for optical computing and communications. Because optics increase the processing speed of computers and transmission clarity and speed of communications systems over their electronic counterparts, these applications also have tremendous commercial potential beyond their military function.

FLCs, when combined with an integrated circuit, can display pixels as small as 60 microns wide, about the same diameter as human hair. With pixel resolution this minute, FLCs could be used in future high-definition television systems. As a bridge to these long-term applications, Displaytech is marketing a family of FLC-based electro-optic shutters and spatial light modulators for research uses, and is considering markets for displays, print bars, fiber optic switches, and instrumentation. Displaytech also is extending research to further reduce pixel size, with a goal of developing 10 micron-thick pixels within two years. With 10 micron-thick pixels, Displaytech could put a million pixels on a watch, equaling the resolution on a typical 12-inch television screen.

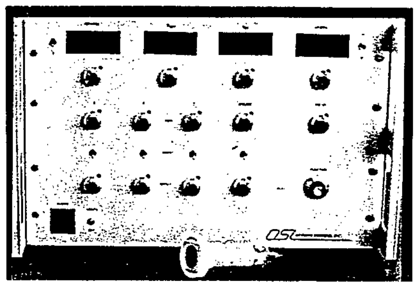
FLCs are made of a liquid crystal film composed of long, rod-shaped molecules. The film is sandwiched within glass plates that serve as electrodes. The long axes of the FLC molecules orient in response to changes in the applied voltage, in the process altering the polarization of the film. As the polarization changes, the film alternately reflects and transmits light. By doing so, the FLC becomes an optical switch.

Compared to other optical switches, FLCs have higher-speed electro-optical properties, and allow faster switching with lower losses of light and power. FLC switches modulate hundreds to thousands of input light beams at gigahertz rates, and connect them to an equally large number of outputs. With fast switching speeds, FLCs also can reconfigure the switch's entire connection pattern in microseconds.

SDI Spatial Light Modulator for a High-Definition Display System

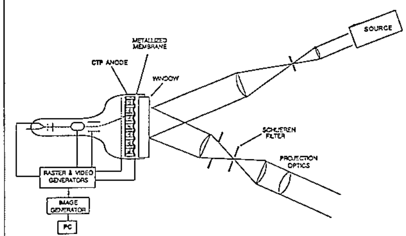


A high-definition membrane mirror projection display system. This system, developed by Optron Systems, Inc. during SDI SBIR contracts, has applications in large-screen high-definition projection displays, flight simulators, medical imaging, and night vision instruments.



A spatial light modulator (SLM) that Optron Systems, Inc. (Bedford, MA) developed under an SDI SBIR contract is the key component in two commercial products: infrared scene projection systems and large-screen projection displays. Optron unveiled these products at the July 1991 SPIE (International Society for Optical Engineering) International Symposium in San Diego. Optron now sells devices for infrared scene projection while continuing research on next generation membrane mirror SLMs for high-definition projection display systems.

Optron's electron-beam-addressed membrane mirror SLM (see sibebar) also could have applications in optical switching, optical computing for target recognition and battle management, projection displays, flight simulators, teleconferencing, workstation monitors, artificial intelligence, medical imaging, night vision instruments, and neural networks.



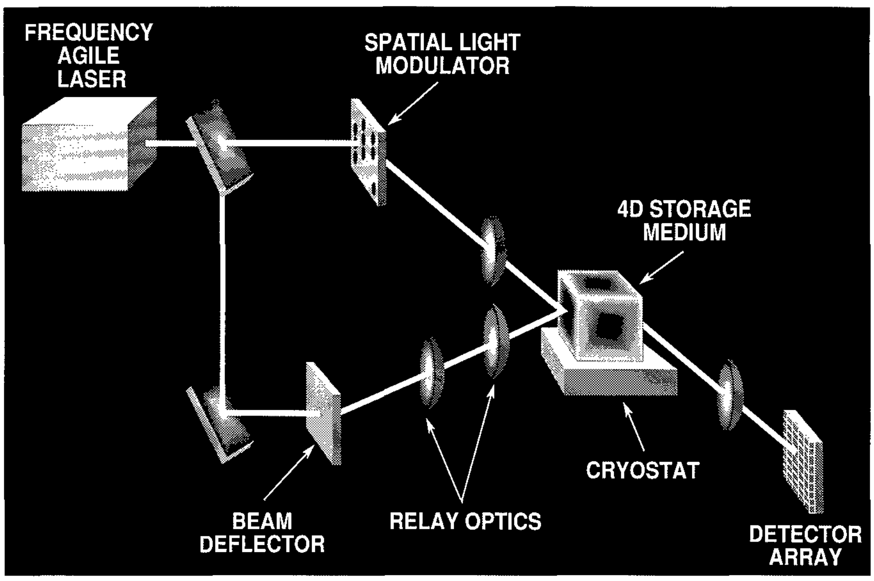
A schematic of the electron-beam-addressed membrane mirror spatial light modulator (SLM). Optron's 2-D SLMs can process electronic signals such as radar return or optical signals in the visible to infrared spectrum. The processed signal is read out by a laser beam that passes through lenses and filters to extract information from the signal.

SDI SPINOFFS
Computers

Optical Data Storage Techniques Provide More Capacity, Quicker Access

Magnetic storage systems, such as disk drives, operate 1,000 to 10,000 times more slowly than typical microprocessor central processing units (CPUs). This comparative slowness causes a major bottleneck when processing large amounts of computer information. Two SDI-sponsored breakthroughs in optical data storage promise to eliminate the access lag between storage devices and CPUs.

Spectral Hole Burning



A schematic of an optical computer that uses a 4-D data storage medium made of spectral hole burning (SHB) material. The SHB material, developed by the Sparta Corporation during SDI SBIR contracts, can retrieve data 1,000 to 10,000 times faster, and can store 10 to 100 times more data, than current magnetic media.

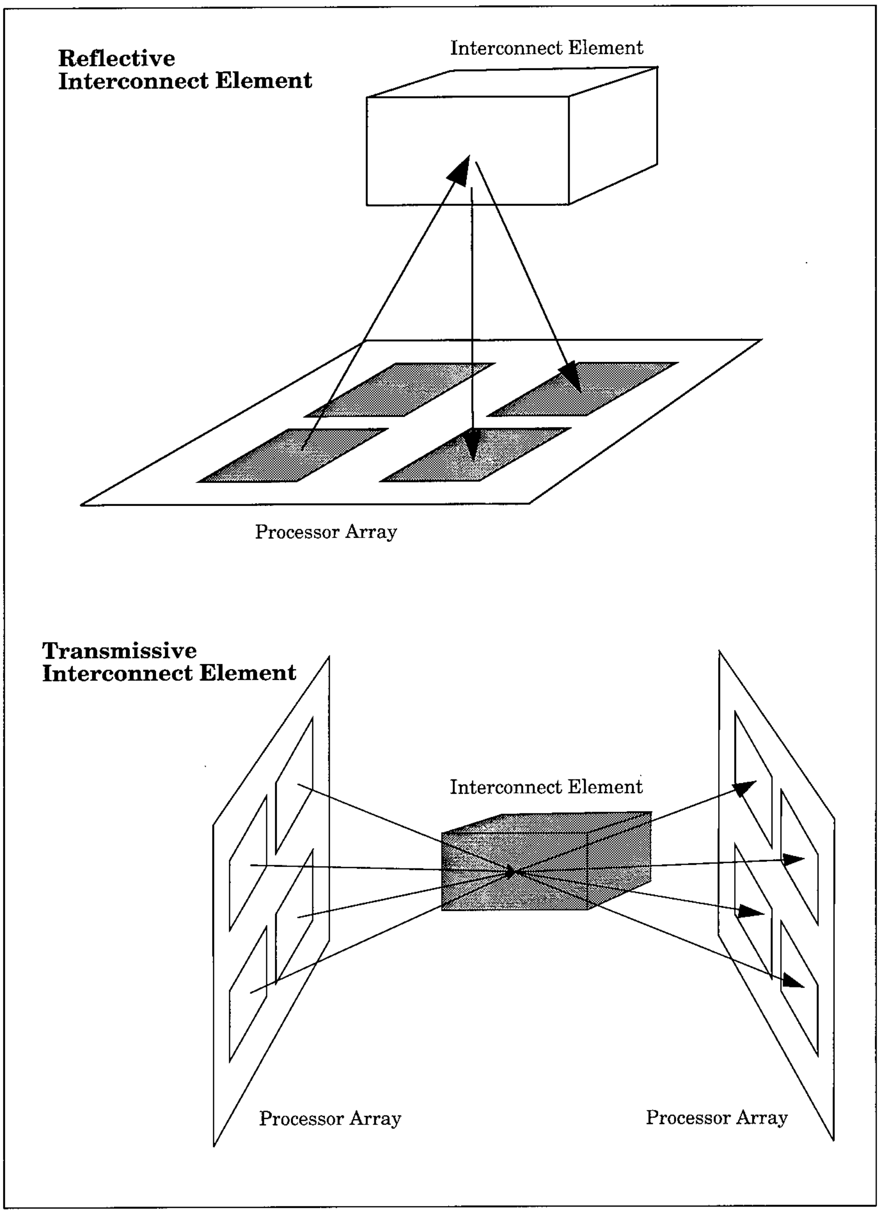
Sparta Corporation (Lexington, MA) is exploring a method to store and retrieve computer data with holograms (see sidebar). This method, developed under SDI SBIR contracts, can store up to 10^{15} bits of data in a cubic centimeter of the storage medium — 10^4 times greater than other optical methods, and 10^7 times more dense than current magnetic disk systems. Because of its storage capacity, the method creates much lighter and more compact data storage systems — which is especially important in space-based computers where every pound increases launch costs by thousands of dollars.

The method, called spectral hole burning, will boost the productivity of computer systems that need to scan through large amounts of data very quickly, such as network file servers, ultra-large on-line databases, real-time interactive video, telephone services (voice mail, FAX, etc.), digital terrain data, on-line map updates, or global climate data. The technology provides rapid access times — less than a millisecond — because there are no mechanical delays, as in hard disks. Spectral hole burning offers a low cost per bit of memory, as low as seven cents per megabyte, compared to $10 to $100 per megabyte for other methods. Sparta has received one patent for the technology, with two more pending.

In spectral hole burning, data is stored in the form of holographic pictures. To do this, the method employs a solid, visually transparent medium (organic polymers such as polyethylene or polystyrene) doped with microscopic color centers (organic dyes such as porphyrin or chlorin). In order to preserve the spectral holograph, spectral hole burning materials must be kept at cryogenic temperatures below -263° C (10 K).

This 4-D optical data storage system (the fourth dimension is wavelength) can read and write data; limited erase functions also are available. To store data, patterns of intense laser light that carry digital data activate the microscopic color centers to produce holograms. Data stored in these holograms can be retrieved by shining low-level laser beams on the color centers. To retrieve data, certain wavelengths of light will stimulate selected holograms to emit the same data-carrying pattern of light used to make the holograms.

Optical Data Storage



Schematics of two optical data storage systems developed at Stanford University during an SDI IS&T contract. Interconnect elements — which can be set up as reflective elements (top) or transmissive elements (bottom) — receive data from input processor arrays, store the data in the form of holographic images, and transmit it to output processor arrays.

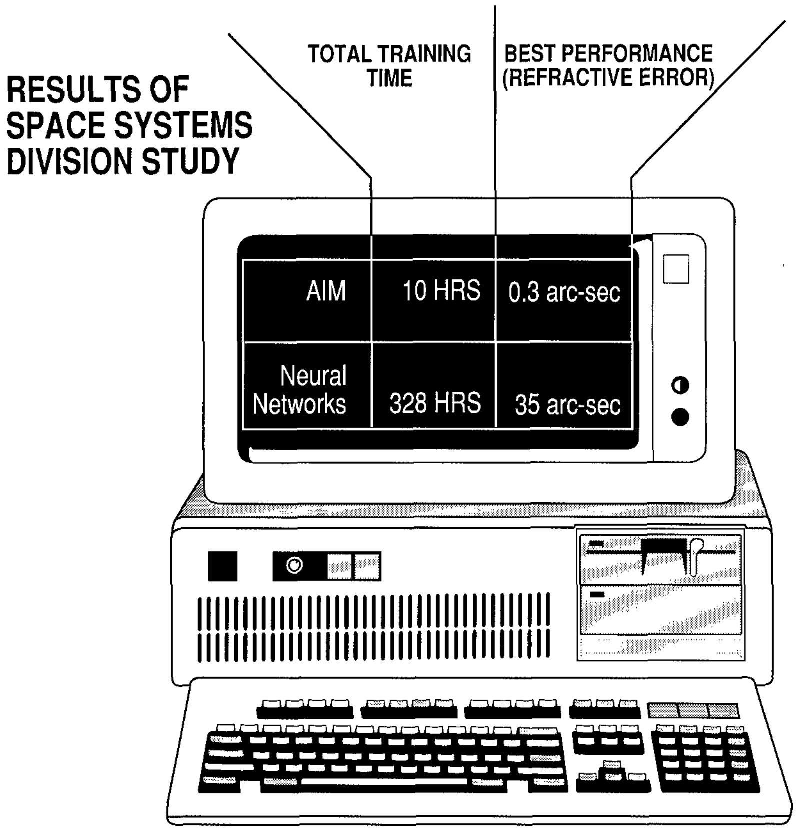
Stanford University (Palo Alto, CA) researchers funded by the SDI IS&T program have developed optical storage devices that can store or retrieve data at CPU speeds (see sidebar). The devices also can store much greater amounts of data (10 to 100 times more) in the same volume as magnetic media storage devices. While the optical data storage technique can work in conventional electronic computers, storage capacity and processing speed can be further increased by incorporating the device into an optical computer. In optical computers, optical information streams can be sent to different parts of the processor simultaneously, even crossing paths without interference or loss of information. This ability dramatically increases processing and memory access speed. Stanford has patented its data storage technique and is now pursuing commercial opportunities for the technology.

In the Stanford optical data storage system, two streams of optical information are combined to transform data into holographic images. These images are stored optically in the recording medium SBN (an abbreviation for $Sr_{1-x}Ba_xNb_2O_6$). SBN is a ferro-electric crystal with photorefractive properties. Because of its unique electro-optic properties, it can record and store extremely dense holographic images (10^{13} bits/cm^3).

During the early seventies, researchers investigated SBN's potential for data storage. At that time, however, researchers could not develop input and output devices to take advantage of SBN's storage capacity. In addition, because it was difficult to fix information in the crystals, repeated readouts of the data destroyed the holograms.

To solve this problem, Stanford researchers place SBN crystals in an electric field. When placed in an electric field, SBN crystals have rapid switching speeds coupled with "electric fixing," which prevents data loss during repeated readouts. With this innovation, SBN crystals provide high storage capacity, rapid data access time, and reliable readouts.

Decision-Making Software Outperforms Neural Networks, Statistical Analysis



Studies performed by the United States Air Force's Space Systems Division found that AIM, which AbTech Corporation developed under an SDI SBIR Phase I contract, produced networks in one-thirtieth less time, and was over 100 times more accurate than neural networks.

Funding from the SDI SBIR program was responsible for advancing the development of expert system software that has gained industry-wide recognition in the field of risk management.

Called "AIM™" for Abductory Inductive Mechanism, the software was developed by the AbTech Corporation (Charlottesville, VA). AIM™ received *PC Week's* highest performance rating when contrasted with three other comparable, commercially available software packages.

The software consists of machine learning algorithms and modeling techniques that merge the neural network concept with advanced statistical techniques to produce a tool exponentially more powerful than either precursor.

AIM™ automatically determines the network structure, node types, and coefficients from a user-provided database. It displays a graphical representation of the completed model that illustrates the relationships among variables and gives the user insight into which variables are important.

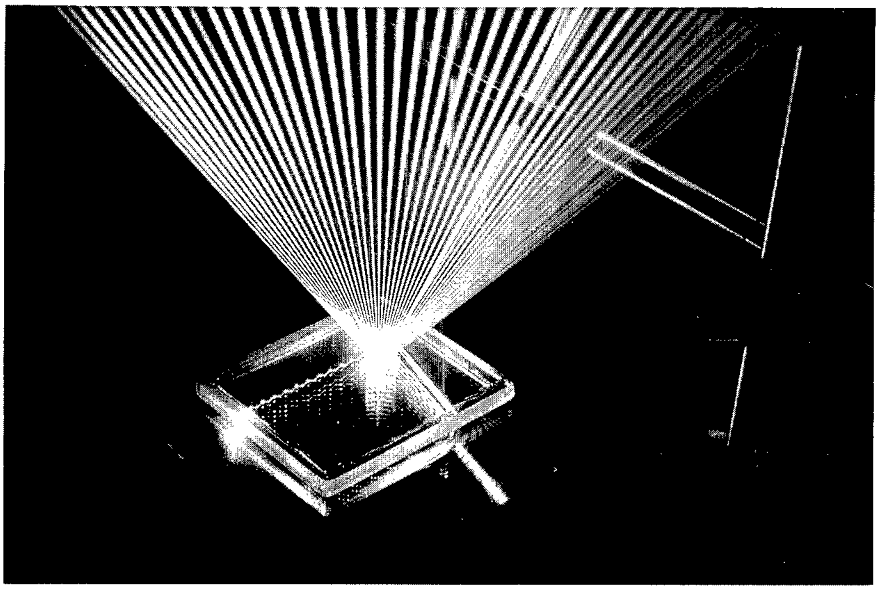
Software developers can embed AIM™ learning algorithms into their own software to create packages that perform automatic remodeling in situations where relationships are constantly changing. Software developers also can use AIM™ off line to produce models that can be exported as royalty-free ANSI C source code subroutines.

Non-military uses of the software are widely varied. The U.S. Department of Agriculture (USDA) uses AIM™ to help farmers control grasshopper infestations. Farmers describe relevant details, including season, temperature, crops grown, and intensity of infestation, and AIM™ recommends the best pesticide for the conditions described. The software is so easy to use that the USDA often sends AIM™ to the farmer on disk for use on the farmer's home computer.

In addition, Citicorp/Choice-VISA™ uses AIM™ to detect credit card fraud. Other corporations using AIM™ include the 3M Company, Union Carbide, Texaco, General Electric, and AT&T. AIM™ is used in cost and inventory estimation, purchasing, quality control, design and simulation, equipment diagnostics, cutting tool life prediction, and yield prediction.

According to a review in the February 1992 issue of *IEEE Spectrum*, "AIM™'s user-friendly interface and ease of application make it far and away the most practical machine learning tool available on the market today. While AIM™ embodies a very powerful mathematics modeling tool, its true power is the ability of the non-specialist to apply it; after all, regardless of how much potential a tool has, it is useless if only a few can apply it."

Optical Waveguides: Components of Ultrafast Optical Computers



Polymer waveguides. These waveguides, developed by the Physical Optics Corporation during SDI SBIR contracts, could serve as high-speed optoelectronic interconnects for optical computers.

Using waveguides that Physical Optics Corporation (POC) (Torrance, CA) developed under an SDI SBIR contract, POC has sold 50 one- to four-channel wavelength division multiplexers (WDMs). These WDMs are used in space-based surveillance networks, commercial computer networks, and communications applications. The graded-index, polymer microstructure waveguides (PMSWs) used to build the WDMs transport and direct light waves for optical signal processing (see sidebar). Other applications include interconnects for very large scale integration (VLSI) chip-to-chip communications, fast multiplexer switches, and microwave digital circuitry.

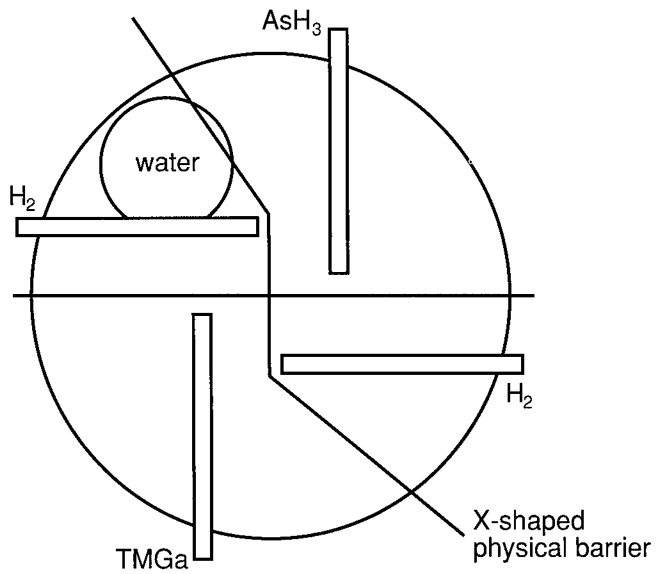
Additional spinoffs from the waveguide technology include fast optical data buses, fan-outs, multichip module optical interconnects, and chip-level spectrometers. The Department of Energy is funding POC to develop a personal computer (IEEE 1014 standard) optical backplane bus to replace the current industry standard Virtual Memory Expansion bus (used to carry data between different components of computers or digital instruments). In addition, POC is affiliated with an R&D team led by Boeing Aerospace to develop an optical backplane bus for an advanced Architecture for Survivable System Processing (ASSP) computer system. The ASSP effort is sponsored by the Air Force's Rome Air Development Center (Rome, NY). Several computer manufacturers have said they may use the optical backplane data bus in future systems, but await proof-of-principle and life cycle testing from POC.

In POC's optical waveguides, a surface-applied gel polymer layer transports optical signals. To trap light, POC treats the polymer layer to produce a graded-index. The PMSW technology works on smooth surfaces of different substrate materials including silicon, gallium arsenide, glass, lithium niobate, metals (e.g., Al, Cr, Au, Cu), Kovar, and ceramics (e.g., Al_2O_3, BeO, AlN). Tests show that the polymer material is thermally stable from -100° C to +180° C, and can withstand exposure to nuclear radiation, electric and magnetic interference, and high-power microwaves.

POC has produced single-mode planar and channel optical waveguides using the PMSW technology. Polymer waveguides offer the following advantages over solid-state optical waveguides:

- The gel polymer layer is pliable and can be applied to flexible substrates such as ribbons, sheeting, and cable.
- The PMSW fabrication process can be less complex and less expensive than conventional waveguide production processes involving chemical vapor deposition (CVD) or molecular beam epitaxy (MBE). Using the PMSW fabrication process, POC has built waveguides as large as 30 x 30 cm on glass substrates.
- Polymers provide higher optoelectronic transmission bandwidths than glass or semiconductors. High bandwidths are valuable for high-speed optoelectronic signal processing.

Rotating-Disk Reactor Grows Semiconductors Layer-by-Atomic Layer



A top view of the atomic layer epitaxy (ALE) reactor that EMCORE Corporation developed during an SDI SBIR contract. This layer-by-layer fabrication process separates the deposition of each layer spatially rather than temporally. This allows manufacturers to control the thickness and composition of a semiconductor on an atomic scale while maintaining high growth rates.

Atomic layer epitaxy (ALE), a process for growing semiconductors an atom-thick layer at a time, has been in use for about twenty years for the growth of compounds for flat screen thin-film electroluminescent displays. While ALE provides greater control of semiconductor growth, it is typically much slower than its chief competitor, metal-organic chemical vapor deposition (MOCVD).

EMCORE Corporation (Somerset NJ), with funding from the SDI SBIR program, is developing an ALE process that combines the layer-by-layer control of ALE and the throughput of MOCVD. This process uses a rotating disk reactor that can produce several wafers at once, and allows a new level of thickness and doping uniformity of atomic layers on substrates. EMCORE anticipates that ALE production will lead to new processes for growing semiconductors on trench sidewalls and highly uniform arrays of quantum-scale devices for optoelectronic integrated circuits. EMCORE also is developing the technique for growing gallium arsenide (GaAs) on a semiconductor substrate.

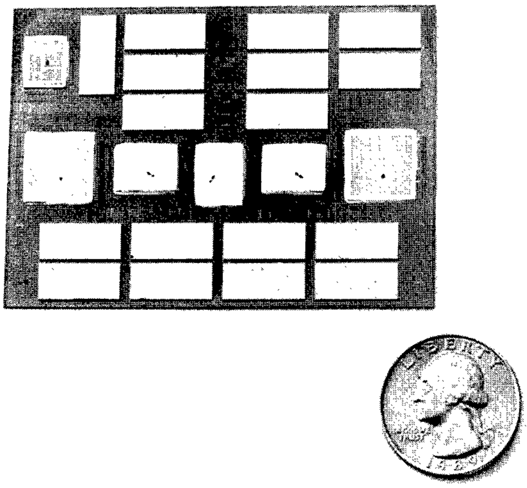
EMCORE's ALE process can produce sensors, high-speed electronic devices, integrated circuits, and displays. EMCORE sold its first ALE system to North Carolina State University.

EMCORE's growth approach uses spatial separation, via continuous rotation, in a segmented, multi-zone reaction chamber to overcome the previous growth rate and mechanical limitations of ALE schemes based on temporal separation. EMCORE has demonstrated ALE growth rates up to half a micron an hour, which is nearly three to five times faster than those reported for ALE temporal separation techniques.

Characteristics of ALE Growth:

- Uniform vapor adsorption
- Uniformity determined by the substrate (not hydrodynamics or reactor geometry)
- Monolayer-by-monolayer self-limiting growth
- Monolayer thickness control of molecular beam epitaxy with the large area/throughput capacity of chemical vapor deposition.

Miniature, High-Speed Computer



A single node of the Space Computer Corporation's multi-node parallel processor, developed under SDI SBIR contracts. The multi-node parallel processor has applications in remote sensing, environmental monitoring, reconnaissance, and surveillance, while image-processing algorithms developed in this project could be used in high-definition television, videophones, and multimedia presentations.

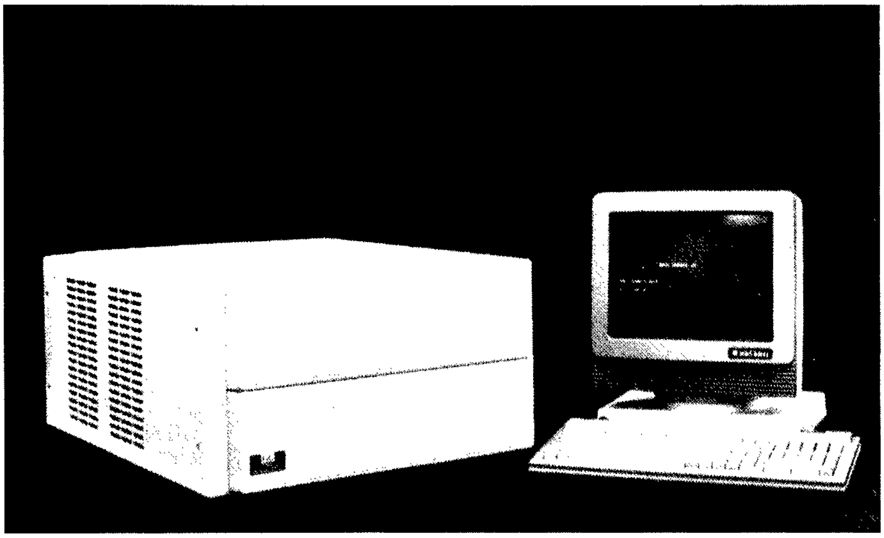
During an SDI SBIR contract, the Space Computer Corporation (Santa Monica, CA) developed an extremely compact, low-power computer to detect and track targets in space. The company has continued development of the computer for remote sensing, environmental modeling, surveillance, and reconnaissance under a Defense Advanced Research Projects Agency contract. In addition, General Dynamics has purchased a 19-node system, while several other companies have discussed using the system.

Under the SDI SBIR contract, Space Computer also developed algorithms that provide major improvements in clutter suppression and weak target detection. The algorithms, which run in real time using sensor data, have widespread commercial applications for high-definition television, videophones, and multimedia presentation systems. Using the algorithms, Space Computer has developed a new technique for compressing full-motion videos.

The Space Computer Corporation computer is a multi-node parallel processor capable of peak throughputs of two GFLOPS. By using a microprocessor and three vector signal processors, each node of the computer architecture can achieve a peak throughput of 100 MFLOPS (10^6 FLOPS).

The node configuration is implemented through hybrid wafer-scale integration. Bare silicon chips are mounted directly to a high-density interconnect network that is built on a silicon substrate (the board in the picture). Multiple substrates are stacked vertically to form an extremely compact 3-D computer. With 20 boards, the total peak throughput is two GFLOPS.

Secure Desktop Computer: Same Security, More Processing Power



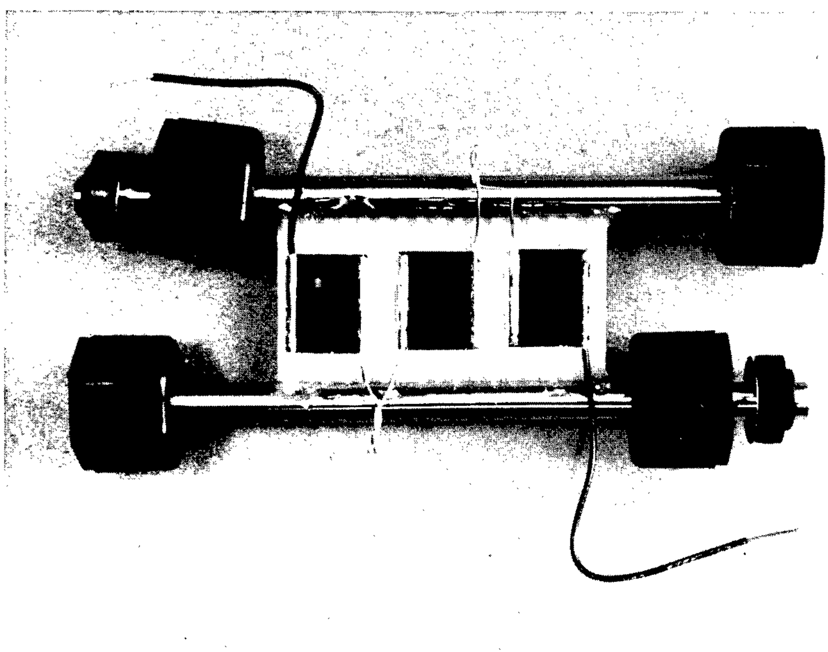
A multi-level secure computer system. Multi-level processing, developed by Gemini Computers under SDI SBIR contracts, allows concurrent processing at different security levels, giving their computers more processing power than other secure systems.

The U.S. Government's "Top Secret" and "Secret" classifications may be the most common expression of defense and intelligence activities requiring secure computer systems. But commercial concerns also have their own computer security needs. Banks must protect financial records, while other companies must guard against industrial intelligence, hackers, and viruses. This need for information security provides a large commercial market for secure computers.

SDI, because of its rigorous security requirements, sponsored work at Gemini Computers (Carmel, CA) through its SBIR program to develop accredited A1 (see sidebar) computers with more processing power than other secure computers. Because computer systems must dedicate valuable processing power to prevent unauthorized access, secure systems usually have limited processing capabilities. Gemini's multi-level secure system, however, has more processing power than other secure systems; it's the "multi-level" that makes this possible. Multi-level processing allows concurrent processing at different security levels. Thus, the most secure levels process work with the highest security requirements, while lower levels process work requiring less security. This approach maximizes computing power without risking security violations.

A1 refers to the Department of Defense's stringent computer security accreditation standards, as defined in the "DoD Trusted Computer System Evaluation Criteria." The National Computer Security Center defines these standards by assigning security levels to computer systems, with Division A the most secure and D the least secure. Gemini designed its desktop computer to meet A1 security criteria, the highest security level within Division A.

Faster, Smaller Computers from Better Cooling Techniques



A prototype multi-chip module built on an aluminum nitride substrate. The aluminum nitride substrate, developed by researchers at the electronics ceramics section of the Naval Research Laboratory under an SDI IS&T contract, will increase cooling efficiency, allowing chips to be placed more closely together on a module.

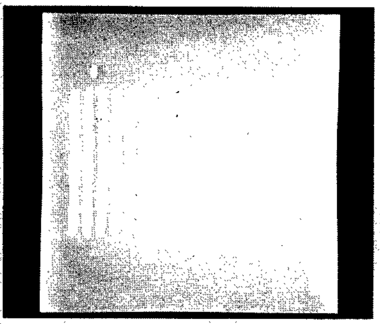
Multi-chip modules, a package of many microelectronic chips mounted on a common substrate, provide closer chip spacing and quicker processing speed than traditional integrated circuits. Cooling these modules, though, is a tricky business. Heat buildup in the module, which can burn out the chips, increases as the power levels and power densities of chips increase, and as chips are placed closer together on a module. To reduce heat buildup in multi-chip modules, the SDI IS&T program funded research at the electronic ceramics section of the Naval Research Laboratory (NRL) (Washington, DC) to design an aluminum nitride (AlN) substrate for multi-chip modules.

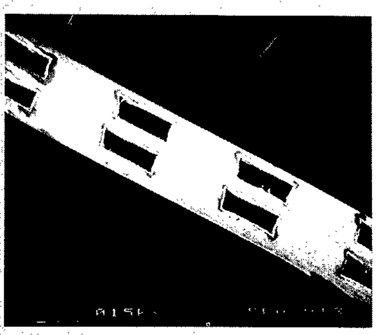
In the SDI-funded project, NRL and the Microelectronics and Computer Technology Corporation (MCC) (Austin, TX), a consortium of computer industry companies, developed an AlN substrate for very high-density, high-power packages. MCC provided expertise in thermal design while NRL provided ceramic technology. MCC now plans to build a working demonstration module with the AlN substrate before transferring the technology to the consortium's member companies.

The NRL group, by discussing their progress with researchers at W.R. Grace & Company, also has advanced W.R. Grace's aluminum nitride research. With this information, W.R. Grace recently built a demonstration module with cooling channels in the AlN substrate.

Compared to other module substrates, aluminum nitride (AlN) has higher thermal conductivity, which allows the substrate to dissipate heat more quickly than other substrates. In addition, it has a lower rate thermal expansion, which means that heat is less likely to alter the structure of the module; it is a better electrical insulator, which means it won't interfere with the circuit's processing capabilities; and finally, designers can build cooling fluid channels through it, which increases the module's cooling capacity.

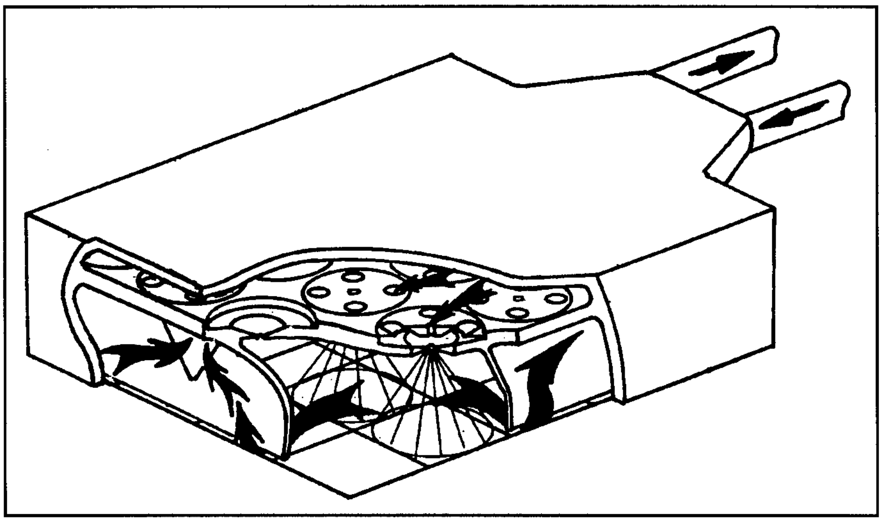
As a result of these advantages, thin, structurally simple, and easily cooled multi-chip modules can be manufactured using an AlN substrate. (The two pictures below show the AlN plate and how the cooling channels are built into the substrate.)





A top view (top) and cross section (bottom) of the aluminum nitride substrate. The pictures show cooling channels built into the substrate, which increase the cooling capacity of the module.

Electronics Performance Improves with Spray Cooling



ISR Inc.'s technique for spray cooling electronic devices (left). ISR was formed as a result of SDI-sponsored research at the University of Kentucky. Arrows in the picture represent the flow of the cooling fluid within the device.

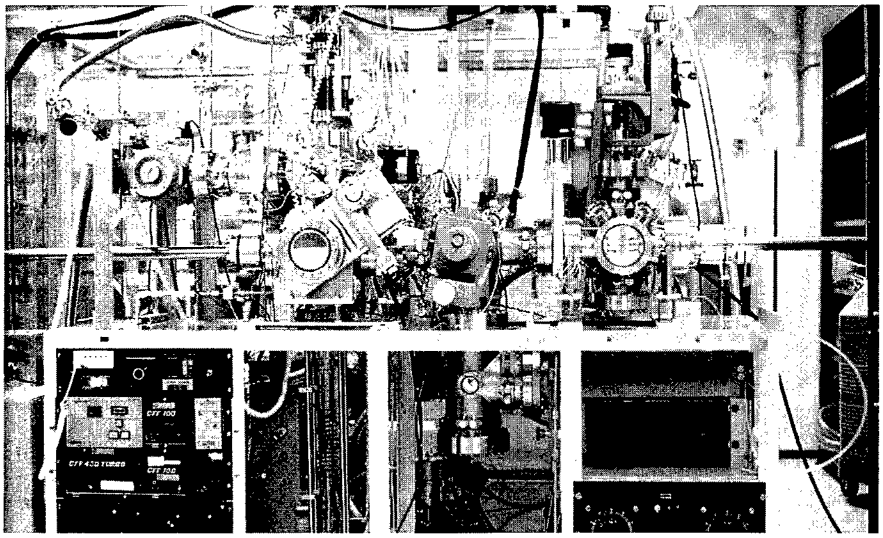
In ISR's spray-cooling technique, droplets mix with hotter fluid on the surface, and dispel nucleating vapor bubbles. Spray cooling also employs an efficient fluid removal technique to maintain thin-film conditions, which promote high-heat transfer rates.

As packaging density increases, electronics grow hotter and heat removal becomes crucial. Isothermal Systems Research (ISR), Inc., a company that spun off from research sponsored by the SDI IS&T program at the University of Kentucky, is confronting cooling needs in electronics with a new spray cooling technique. Spray cooling evolved from SDI-sponsored research on a shell and tube condenser and a low mass liquid/vapor separator suitable for microgravity power and refrigeration systems.

Because spray cooling can uniformly deliver cool fluid over an entire surface area, the technique is more efficient than other direct-immersion cooling technologies. By cooling more efficiently, electronic devices using spray cooling will be lighter, smaller, and more reliable.

These advantages make spray cooling of particular interest to at least three major industries — computers, electronics, and aerospace. Potential applications of the spray-cooling technology include cooling systems for computers, phased-array radar, laser diodes, solid-state radio-frequency devices, and power electronics in high-performance military and commercial aircraft.

Computer Chip Purity Enhanced with New Silicon Growth Process



The Remote Plasma Chemical Vapor Deposition (RPCVD) system at the University of Texas, funded by the SDI IS&T program. As a low-temperature, high-growth-rate process, RPCVD could give semiconductor manufacturers a high-quality, low-cost manufacturing technique for microelectronic devices.

Improved processes for producing semiconductor wafers could cut the price of electrical devices, improve their quality, and invigorate this sector of the U.S. manufacturing base. Researchers at the University of Texas at Austin, sponsored by the SDI IS&T program, are investigating remote plasma chemical vapor deposition (RPCVD) for growing layers of silicon and germanium-silicon alloys on silicon wafers. Spinoffs from this work include:

- A low-temperature way to remove oxygen, carbon, and hydrogen impurities from a silicon surface.
- Improved design of ultra-high vacuum, ultra-high purity gas distribution systems, which are needed for wafer production. Sematech and other integrated circuit manufacturers have inquired about these new designs for their own use.
- Information to help build RPCVD systems for low-temperature material growth.
- Improved accuracy and reproducibility of Auger spectroscopy, a well-known technique used to find impurities on a silicon surface (see the end of the sidebar).
- New production techniques for germanium-silicon structures. Researchers at the University of Texas are developing these structures for both high-speed and optoelectronic applications.

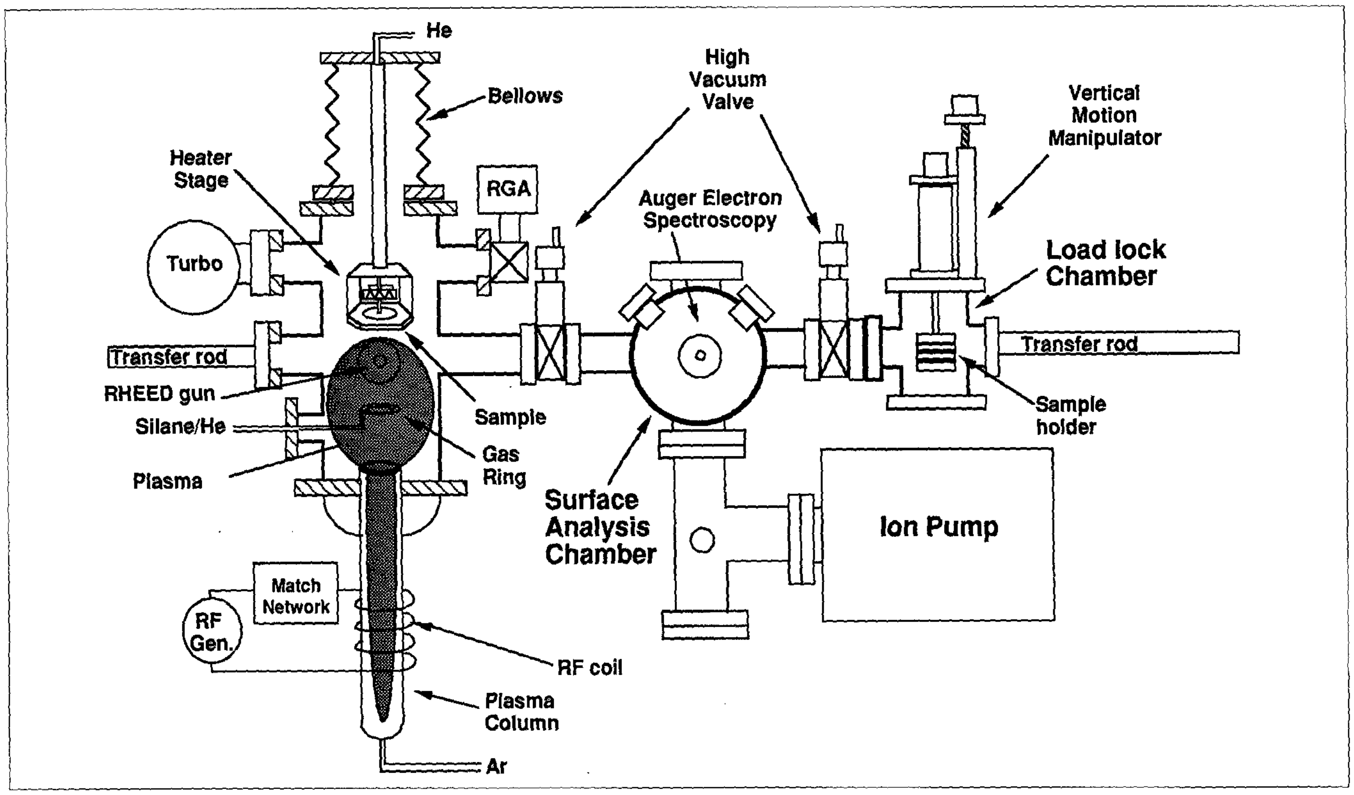
While RPCVD is still in the early stages of development, it could directly transfer to commercial chip-makers. The SDI-funded work has led to a National Science Foundation grant to investigate similar techniques for a variety of elements with an atomic structure similar to silicon. In addition, the work has led to two inventions. So far, one of these inventions has been patented — a technique to produce calcium fluoride (a molecule that was the focus of the group's early work because its crystalline structure is similar to silicon's).

The RPCVD process developed at the University of Texas operates at much lower temperatures than other processes (150°-450° C, compared to 500°-800° C), and has silicon growth rates as high as 0.4 micrometers per hour. RPCVD has demonstrated a world record low temperature of 150° C for silicon epitaxial growth.

A key feature of RPCVD exploits the natural passivating effect (preventing absorption of impurities) of hydrogen on a silicon surface. In RPCVD, a hydrogen-saturated silicon wafer is placed in a plasma chamber containing plasma-excited argon gas and silane (SiH_4). The argon ions in the excited gas cause hydrogen to leave the silicon surface, which immediately absorbs silane molecules to replace the departing hydrogen atoms. When the silane bonds to the silicon surface, it leaves a terminating hydrogen atom that prevents the surface from absorbing impurities such as carbon and oxygen.

RPCVD produces sharp doping profiles (putting another element such as boron into a silicon chip to make the chip act as a semiconductor). In the finished material structure, the process has produced among the sharpest doping profiles ever reported, 10 times better than other processes.

To test RPCVD results, the University of Texas researchers also refined Auger spectroscopy techniques, which are used to measure impurities on silicon chips. In Auger spectroscopy, researchers focus an electron-beam onto the silicon surface. The electron beam causes the silicon surface to emit surface electrons. This emission reveals the composition of the surface, allowing researchers to determine if there are any impurities in the material. Scientists have long known that the electron beam causes elements to leave the surface of the material; the University of Texas research team discovered that the electron beam also causes the material to absorb elements such as carbon and oxygen. Thus, the research team has changed Auger spectroscopy procedures to reduce the time of electron beam exposure. The new procedures prevent misleading data about a material's purity and prevent unwanted impurities from being introduced onto the material.

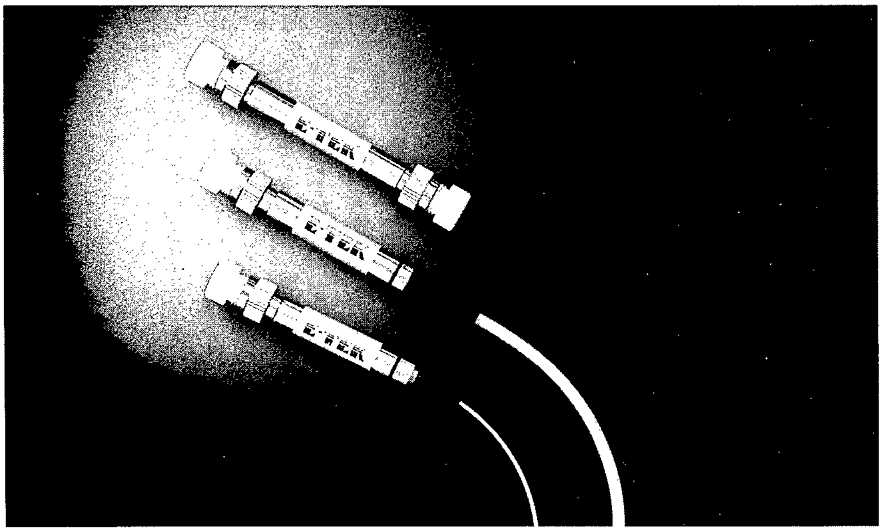


A schematic of the RPCVD system. The actual RPCVD process occurs in the deposition chamber (left), while researchers check the purity of the chip using Auger spectroscopy or other techniques in the surface analysis chamber (center), and load chips in the system and bring them to an ultra-high vacuum without contaminating the other two chambers in the load lock chamber (right). The transfer rod on the left moves chips between the surface analysis chamber and the deposition chamber, and the rod on the right moves chips between the load lock chamber and the surface analysis chamber.

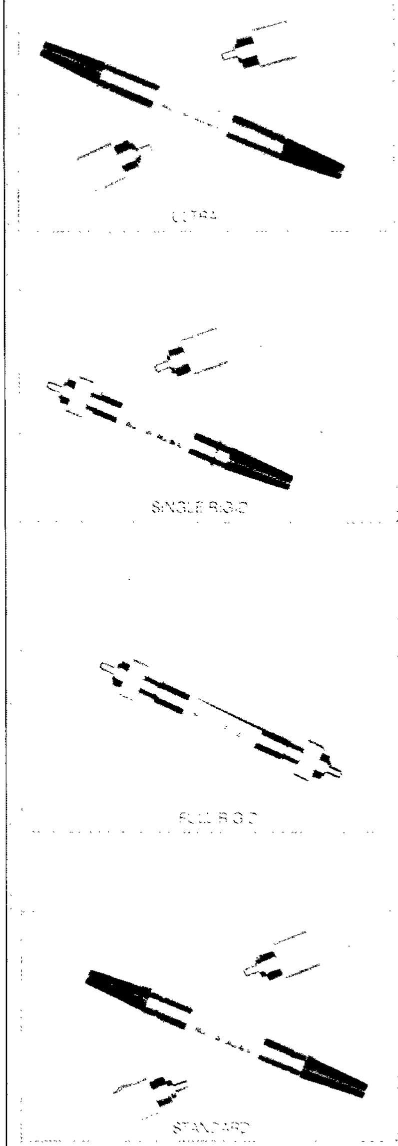
SDI SPINOFFS

Communications

Telecommunications Equipment Benefits from Target Tracking Components



Fiber optic isolators that E-Tek Dynamics, Inc. developed during SDI SBIR contracts for a ballistic missile tracking system (above and right). These components, used in fiber optic communications, are smaller, cost half as much, and offer better performance than competing fiber optic isolators.



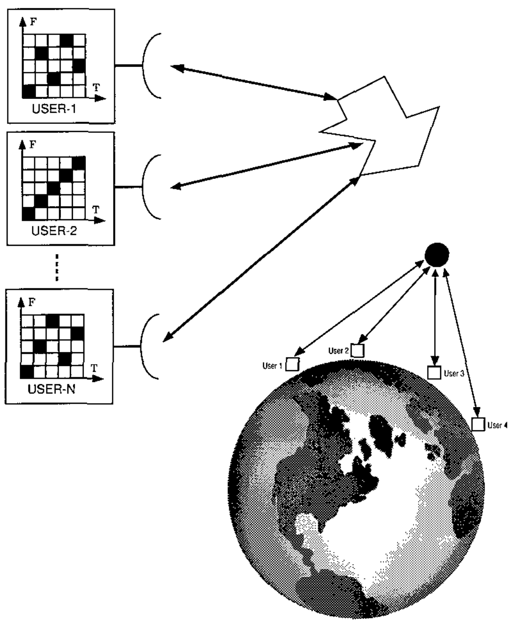
SDI SBIR contracts to develop an optical target tracking system provided E-Tek Dynamics, Inc. (San Jose, CA) with the chance to design optoelectronic components that outperform similar, previously available devices. These performance gains have supplied E-Tek with a new product line in telecommunications.

The first product, a fiber optic isolator, eliminates the reflection of light in laser-based fiber optic systems. They can be used in fiber optic communications systems, cable television fiber optic links, military microwave and radar systems, and optical amplifiers. Competing isolators are larger, cost twice as much, and do not suppress optical reflections or reduce system noise as well as E-Tek's fiber optic isolators.

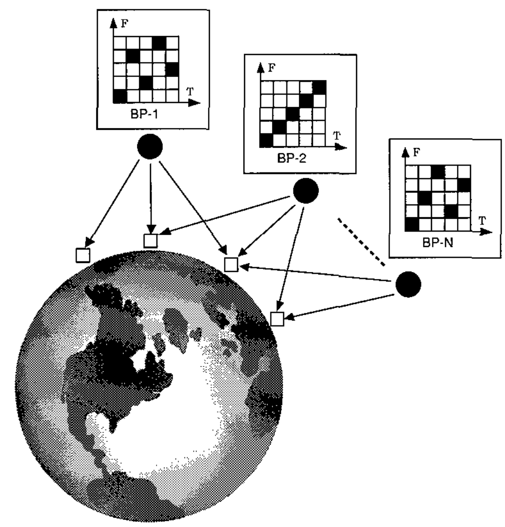
Other E-Tek target tracking system components include laser sources, polarization controllers, and integrated phase-shifters — all of which can be used in telecommunications systems. In such systems, the integrated phase-shifters and other components modulate signals traveling through telephone fiber optic cables at extremely high speeds. High-speed modulation is possible because E-Tek's components work in the picosecond (one trillionth of a second) range. This is considerably faster than other telecommunications components. Because of these performance advantages, several telecommunications companies have expressed interest in E-Tek's components for their systems.

In the long term, E-Tek's optical target tracking system could be used for aircraft anti-collision systems, robotic vision, wide-angle security surveillance, and a system to combine laser beams into a single, high-power beam for laser surgery. This optical sensor system, because it uses multiple apertures to emit laser beams, works much like the compound eye of a bee to increase field-of-view (over a hemisphere wide) and track multiple targets. The system also can simultaneously steer multiple laser beams to improve its accuracy and speed.

Increasing the Number of Cellular Phone Channels with New Coding Algorithm



Multiuser Radar



Brillant Pebbles sensors

Applications of congruential coding: multi-user radar and Brilliant Pebbles. The checkered boxes represent code arrays used to distinguish different signals that can be sent to different users (left) or transmit information from SDI's Brilliant Pebbles sensors (right).

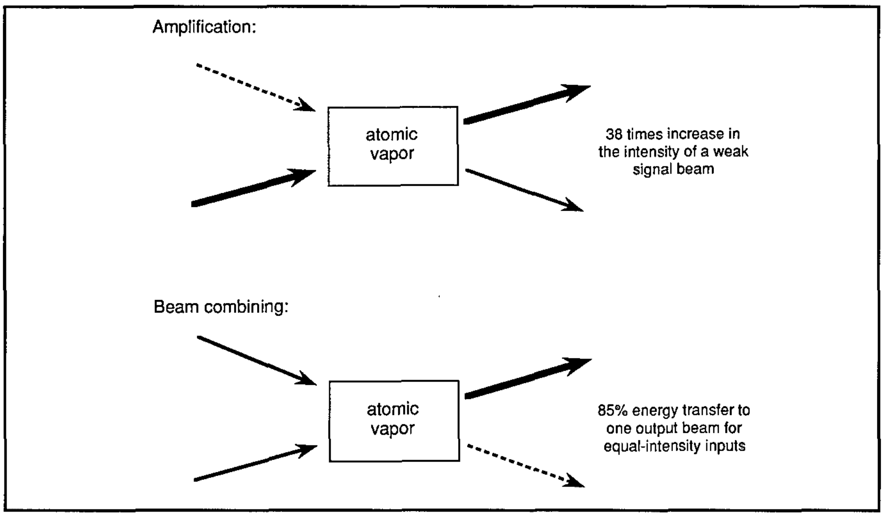
A "congruential coding" algorithm developed at University of Rochester (Rochester, NY) under an SDI IS&T contract gives communications systems one-to-one access by finding the correct signal and blocking out all other signals (see sidebar). With one-to-one access, congruential coding could allow more users in a code division multiple access (CDMA) cellular telephone system than current coding techniques. Also, computer networking systems and sonar, radar, and satellite communications could use congruential coding techniques to reduce signal noise.

In the SDI application, congruential coding should increase the number of channels in multi-user radar and spread-spectrum communications systems. In addition, the Navy is developing congruential coding to detect and classify submarines. By doing so, torpedoes could better distinguish between their own sonar signals and other, stray signals — thus making it easier to lock onto their targets.

The University of Rochester has won a contract with the Rochester Gas and Electric Corporation (RG&E) to develop an alarm system using this technology. With the University of Rochester's coding technology, the alarm system will be able to detect line and equipment failures and then transmit this information to the emergency center of a power distribution network, even in adverse conditions (such as bad weather). With traditional technologies, it is difficult to transmit many signals or discriminate among simultaneously transmitted signals in these conditions. By using this technology, RG&E will be able to more accurately locate line and equipment failures.

The problem that coding addresses is much like conversations between people. When only two people are talking, there is no real possibility of misunderstanding who you are addressing. But in a crowded room, you can say someone's name (Ted) and three people will turn their heads (Tim, Tom, and Ted), all of them thinking you called their name because the noise in the room has distorted the sound of your voice. Coding, however, allows you to address someone without misunderstanding, no matter how noisy the "room."

Increasing Laser Beam Power for Communications



Amplifying (top) and combining (bottom) laser beams in a vaporized gas. This technology, developed by University of Rochester researchers during an SDI IS&T contract for laser communications, also could be applied to fiber optic transmissions to provide low-noise, undistorted signals for telecommunications.

By combining several laser beams into a single, high-power beam, researchers at the University of Rochester (Rochester, NY) are improving the transmission power of laser communications systems. This research, sponsored by the SDI IS&T program, has led to joint research with Allied Signal to combine beams emitted from alexandrite lasers. This research, which focused on short optical pulses of extremely high intensity, has created a new technique for locking laser beam frequency and intensity during transmission.

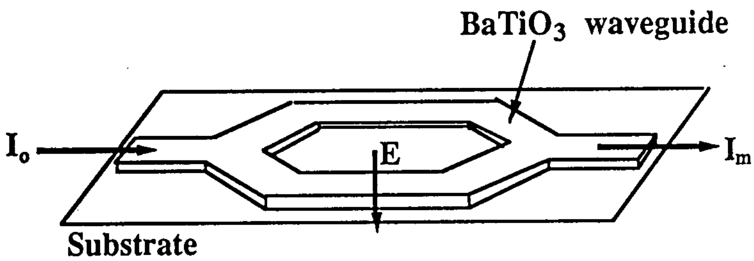
This research also spawned another project sponsored by the Air Force's Rome Air Development Center in which the University of Rochester has received support from the New York State Center for Advanced Optical Techniques and Eastman Kodak Company. In this project, the University of Rochester is developing a way to combine and amplify two weak satellite signals. The same idea could be applied to fiber optic transmissions to provide low-noise, undistorted signals for telecommunications.

The technology also could be used to improve the effectiveness of laser surgery techniques. So far, three patents have been awarded for technology resulting from this work. The University of Rochester has retained patent rights for its work.

University of Rochester researchers are increasing laser beam intensity and quality through several techniques. In one method, researchers combine laser beams in a vaporized gas of sodium (or potassium). These atomic vapors can handle high laser intensities, and thus can combine laser beams with high energies. In addition, atomic vapors absorb very little of the laser beams' energy and do not easily break down. During the project, the researchers achieved a 38-fold increase in the intensity of a laser beam. They also transferred 85 percent of the total incident energy to one of the output beams.

The researchers also developed a technique for correcting polarization and wavefront distortions using four-wave mixing. In four-wave mixing, three input beams combine at precise angles in an atomic vapor to form a fourth, undistorted output beam.

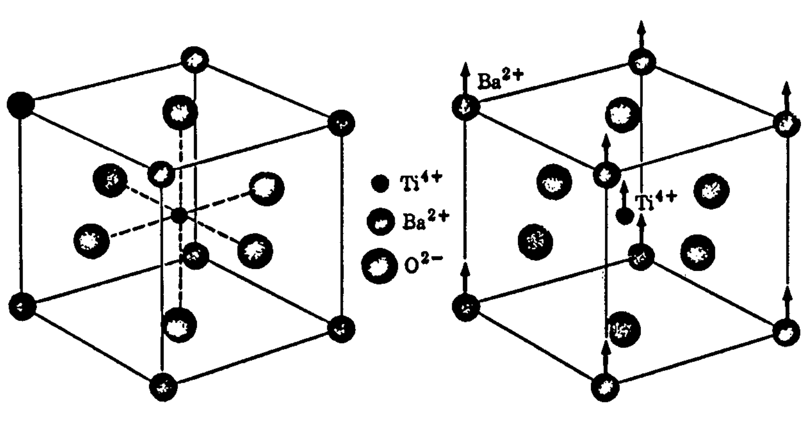
Telecommunications, Imaging to Benefit from Barium Titanium Oxide Integrated Circuits



An electro-optic modulator, as would be made with Advanced Technology Material's cost-effective thin-film $BaTiO_3$ manufacturing process. The SDI SBIR program is funding development of this process under a Phase II contract.

Future electronics miniaturization and integration processes will rely on thin-film optical materials, which would cut cost and size and boost performance of telecommunications devices, medical imaging systems, motion sensors, fire detectors, and pre-fire alarms. In an SDI SBIR Phase I project, Advanced Technology Materials (ATM), Inc. of Danbury, CT, was the first organization to grow thin-films of Barium Titanium Oxide ($BaTiO_3$) with controlled crystalline orientation. $BaTiO_3$ is an exceptional thin-film candidate material (see sidebar).

SDI funded the base technology to develop planar optical waveguides for optical switching, optical data processing, and photonic switching applications. ATM's technology also can be applied to integrated optics functions such as electro-optic modulators, frequency doublers for diode lasers, photorefractive or holographic DRAM or non-volatile memory, and room temperature pyroelectric infrared radiation detectors. ATM anticipates commercial sales of products developed with its $BaTiO_3$ process to begin by the end of 1993.



The crystalline structure of $BaTiO_3$.

$BaTiO_3$ is an exceptional thin-film candidate material because it has the largest photorefractive effect known and is among the highest known electro-optic effects (optical properties). $BaTiO_3$ also displays ferroelectric and pyroelectric effects and has a high dielectric constant (electronic properties).

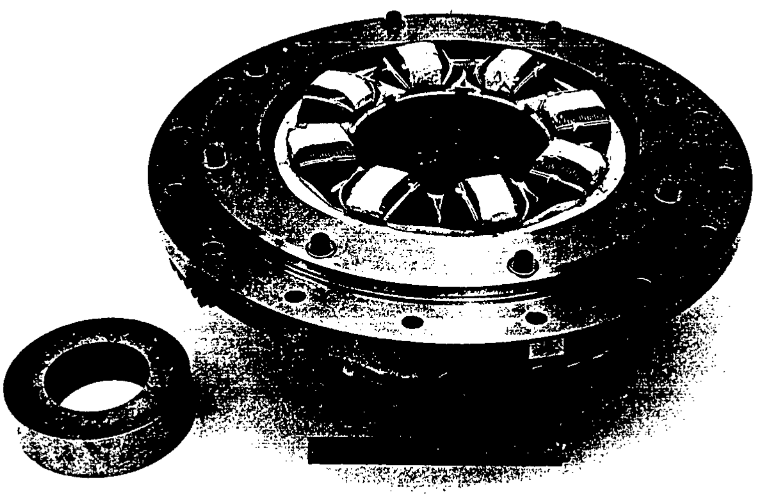
ATM used a unique metal-organic chemical vapor deposition (MOCVD) process and a strontium titanate ($SrTiO_3$) substrate to grow the films in two different crystalline orientations ([100] and [110]). Subsequent research resulted in epitaxial $BaTiO_3$ on a neodymium gadolate ($NdGaO_3$) substrate. With SDI SBIR Phase II funding, ATM is refining its MOCVD process to fabricate epitaxial $BaTiO_3$ thin-films for frequency doublers.

ATM also has performed research on $BaTiO_3$ - $SrTiO_3$ Dynamic Random Access Memory (DRAM) for SDI in another Phase I SBIR project, and has examined plasma enhanced MOCVD of $BaTiO_3$ in an NSF SBIR Phase I project.

SDI SPINOFFS

Industry

Reliability, Performance of Mechanical Systems Improved with Magnetic Bearings



Magnetic bearings developed by SatCon Technology Corporation during SDI SBIR contracts. By reducing friction, wear, and vibration in moving parts, these bearings improve performance of large, high-speed mechanical systems.

In magnetic bearings, moving parts "float" in a magnetic field without contact to nearly eliminate friction and wear. By doing so, magnetic bearings enhance performance and increase the lifetime of motors, compressors, and turbines that previously used conventional lubricant-based bearings. Under SDI SBIR contracts, SatCon Technology Corporation (Cambridge, MA) has developed a magnetic bearing system for SDI's space-based power generators that reduces not only friction and wear, but also vibration in moving parts (see sidebar).

SatCon's magnetic bearings are particularly useful in large, high-speed systems subject to strong vibration or unusual amounts of wear. So far, SatCon's focus has been on military applications, although the technology could replace traditional bearings in automobiles, refrigerator and air conditioner compressors, and other machinery.

Other projects in which SatCon has used its magnetic bearing technology include:

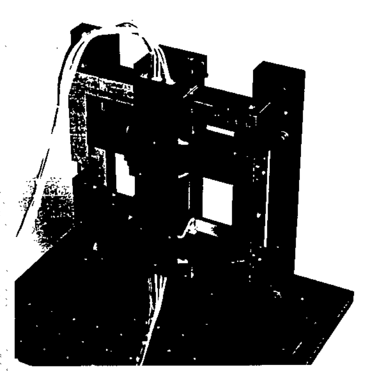
- A heat pump compressor that uses magnetic bearings (see page 17). This compressor, also funded by SDIO, will initially serve as a heat pump for spacecraft, but may have commercial applications in refrigeration and air conditioning.

- A magnetic suspension test bed for the Naval Weapons Center. The test bed uses magnetic fields to measure torque and tension in products to be used in fiber optic-guided missiles.

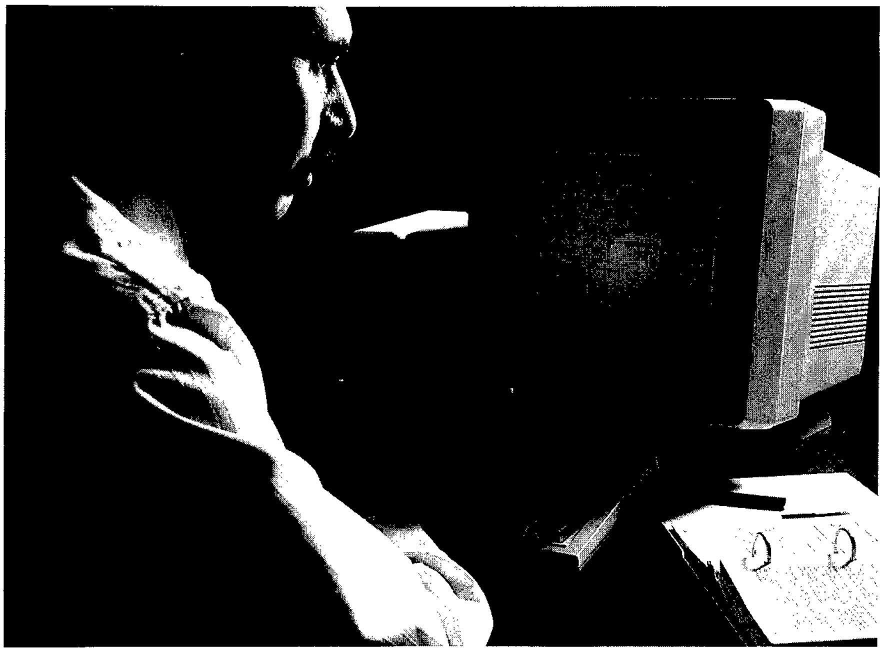
- A main propulsion motor for ships. This electric motor was funded by the Navy and the Defense Advanced Research Projects Agency.

- A gas turbine engine for aircraft. This project is part of the Army Aviation Systems Command's Initiative for High-Performance Turbine Engine Technology (IHPTET), and could eventually be used in commercial aircraft. Magnetic bearings will increase the gas turbine engine's thrust-to-weight ratio by reducing the engine's weight and increasing its power. Magnetic bearings will reduce weight by eliminating the loop system that circulates oil for lubrication, and increase power by allowing the turbine to rotate at higher speeds.

SatCon's magnetic bearings consist of a rotor surrounded by magnetic actuators. The actuators produce a magnetic field that holds and guides the spinning rotor. In a closed system (one with no external forces applied to the rotor), magnetic bearings require only these actuators. However, because a variety of external forces can throw the rotor out of alignment, the magnetic actuators must compensate for these forces. When external forces are applied to a rotor, a system of sensors respond by transmitting this information to a controller. The controller, in turn, sends a signal that directs the actuators to produce magnetic fields that will counteract the external forces.



SimTool™ – Rated Best Software for Designing Thermal Management Systems



Researchers using SimTool™, a simulation program that models thermal management systems. Mainstream Engineering Corporation developed SimTool™ under an SDI SBIR Phase I contract.

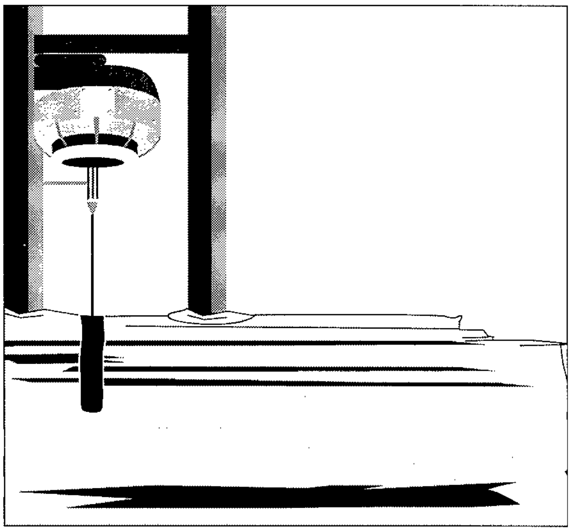
Rockwell International recently studied several different thermal management software programs and evaluated them for the following characteristics: the most user-friendly, current, available, valid, compatible, and convertible. Other criteria included which program maintained the best balance between cost and speed, and which one could be the most easily integrated with other systems. SimTool™, which the Mainstream Engineering Corporation (Rockledge, FL) developed under an SDI SBIR Phase I contract, received the highest overall rating.

SimTool™ models fluid/thermal systems including heat pumps, hydraulic systems, and two-phase or single-phase loops. SimTool™ takes user inputs to build a thermal management system, automatically determines the system flow path, and provides flow rate and flow reversal calculations. Inputs include system devices or components, and over 1,000 different working fluids that can be selected from a SimTool™ library. In addition, the program allows users to design their own components and devices, or add new fluids to the library.

Mainstream has sold nearly 500 SimTool™ programs, generating annual revenues of over $1 million. With the release of an expanded version, Mainstream expects 1992 revenues to double. Mainstream provides extensive marketing and support services for the program, including a quarterly newsletter, an 800 telephone number, and a product support team to answer users' questions. A demonstration disk of the program is available.

Pulsed-Power for Industrial Applications

SDI SBIR funding has helped Tetra Corporation (Albuquerque, NM) become a leader in pulsed-power research and development. With pulsed-power research designed for SDI's Directed Energy Weapons program, Tetra has produced commercial laser systems, medical accelerators, particle beam accelerators, and pulsed x-ray sources.



A conceptualization of a pulsed-power generator used to drill wells through rock. SDI SBIR research contracts for pulsed-power systems have allowed Tetra Corporation to develop such a drill, as well as commercial laser systems, medical accelerators, particle-beam accelerators, and pulsed x-ray sources.

Because Tetra's pulsed-power technology provides very high peak powers in a compact package, the company has negotiated with several major corporations and national laboratories to use its pulsed-power technology for construction, materials processing, mining, and military applications. For example, Tetra is working on a new technique to pulverize metallic bearing ore and separate the ore from the rock matrix. A major mining company is funding Tetra to develop this technology into a commercial product. Tetra also is working on a new technology to drill wells through rock. Tetra has licensed this technology to a major manufacturing company.

Tetra also has developed a microstack insulator that prevents flashover across vacuum insulators, where voltage "flashes" through vacuum tubes. This vacuum flashover is one of the primary problems in pulsed-power applications that require high-current flow in a vacuum. Tetra's microstack insulator technology enables designers and pulsed-power engineers to reduce the size and increase the efficiency of systems operating with high voltage and high currents in a vacuum. The technology has commercial application to x-ray generators, electron-beam industrial process machining, high-power pulsed lasers, scanning-electron microscopes, and microelectronics.

Tetra has filed patents for the microstack insulator and other pulsed-power technologies. The company has negotiated with two national laboratories to develop a version of the microstack insulator for two different accelerators. Negotiations also are underway with an industrial research firm to develop an insulator for their accelerator.

Tetra's pulsed-power research projects for SDI have helped develop compact, highly reliable pulsed-power systems for use in several industrial applications. The following five developments occurred during these research projects, all of which have contributed to Tetra's pulsed-power systems:

- **High-power, low-impedance transmission lines**: By using a lucite/polycarbonate material, Tetra produces transmission lines that are much lighter than conventional lines, which greatly reduces the size, weight, and complexity of pulsed-power systems. The lines handle up to 500 kV at approximately 2 ohms.

- **Closed-cycle repetitive switches**: Many switches in pulsed-power systems require gases that are vented after use. The closed-cycle repetitive switch is designed to recycle switch gases, thereby reducing operational costs.

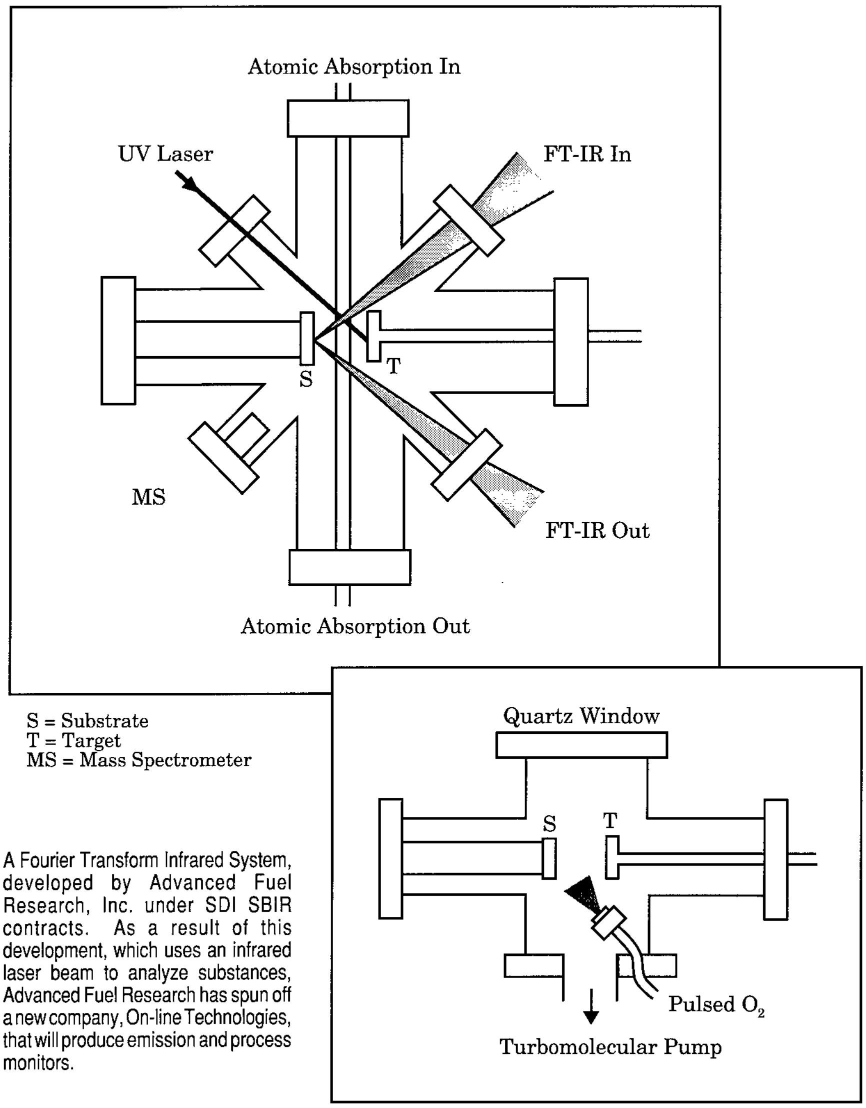
- **Pulsed-power instrumentation using fiber optics**: Fiber optics isolate sensor and control signals in the high-noise environment in which pulsed-power instrumentation operates. As a result, fiber optics simplify design and make pulsed-power systems more reliable. They also improve response for measurements of voltage and current, and provide low-jitter command-and-control signals.

- **Advanced high-power switches**: These switches are compact, are easily triggered, and can manage high current at moderate voltage. They have special applications when remote triggering and reasonably high currents at moderate voltages are required. The switches are very reliable and durable.

- **Microstack insulator**: High-voltage, pulsed-power systems typically use polymeric or ceramic insulators to reduce vacuum flashover. Tetra Corporation's microstack insulators have many advantages over traditional insulators, including lower weight and smaller size for equivalent voltage hold-off. In addition, Tetra's insulators suppress vacuum flashover more effectively than traditional insulators, resulting in stand-off electric fields close to fundamental vacuum breakdown limits. As a result, these compact insulators lower system inductance (a problem that reduces system efficiency).

Licenses are available for each of these Tetra-developed technologies.

Monitoring Industrial Processes



S = Substrate
T = Target
MS = Mass Spectrometer

A Fourier Transform Infrared System, developed by Advanced Fuel Research, Inc. under SDI SBIR contracts. As a result of this development, which uses an infrared laser beam to analyze substances, Advanced Fuel Research has spun off a new company, On-line Technologies, that will produce emission and process monitors.

Under an SDI SBIR contract, Advanced Fuel Research, Inc. (East Hartford, CT) developed Fourier Transform Infrared (FT-IR) technology that has spun off a new company, On-Line Technologies, Inc. On-Line Technologies will produce emission monitors and process monitors for the electric utility, pulp and paper, and waste incineration industries. On-Line Technologies estimates that the market for FT-IR instrumentation for these applications will be $76 million in 1996, and the company expects to capture 15 to 40 percent of the market.

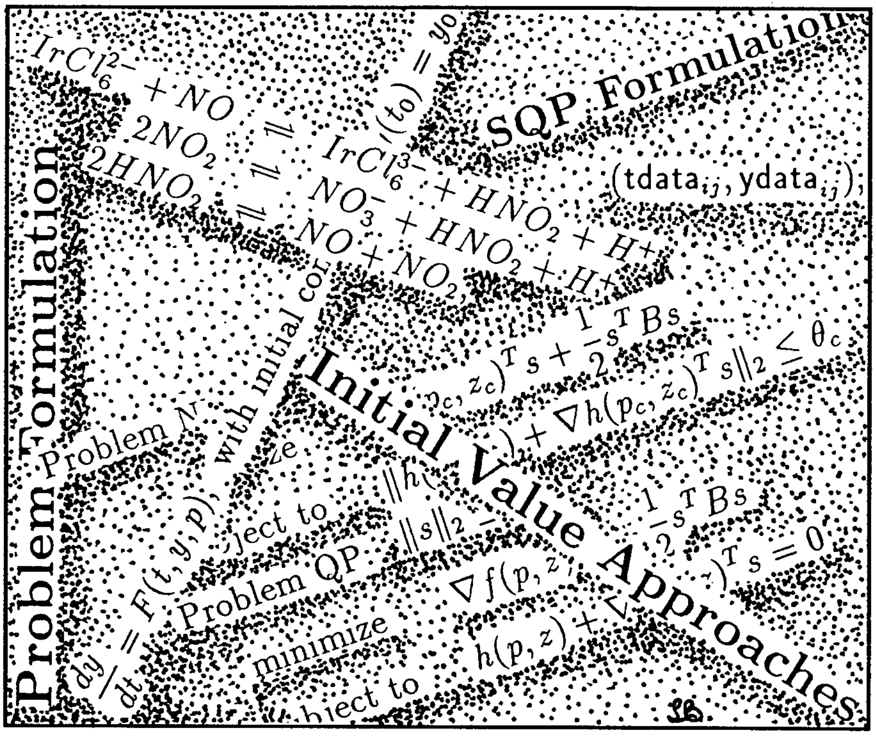
FT-IR technology uses an infrared laser beam to make the substance under analysis emit light waves. The resulting spectra produced by these light waves reveal information about the substances' composition, temperature, or thickness. A computer processes this data in real time using a fourier transform algorithm.

Advanced Fuel Research, Inc. developed FT-IR technology for SDI to monitor the growth of high-temperature superconductor thin-films. The FT-IR system allows researchers to see how the material's properties change as the film grows. Compositional information, film thickness, gas-phase measurements, and temperature can all be determined using FT-IR spectroscopy.

Advanced Fuel Research also can apply FT-IR to the semiconductor production industry. With this technique, manufacturers can determine temperature, composition, and film thickness during semiconductor fabrication. The company, along with Texas Instruments and Varian Associates, is adapting the technology to measure the film thickness and composition of semiconductors as they are being manufactured. Advanced Fuel Research hopes to incorporate this technology into a feedback loop so that manufacturers can optimize chip composition in real time during production. Advanced Fuel Research has filed a patent application for the technique of monitoring surfaces using FT-IR.

Another technique using FT-IR technology, which measures the temperature of oxides, has been patented. Advanced Fuel Research plans to apply this technique to temperature monitoring for the glass-making industry.

Predicting Changes in Chemical Processes with New Algorithm

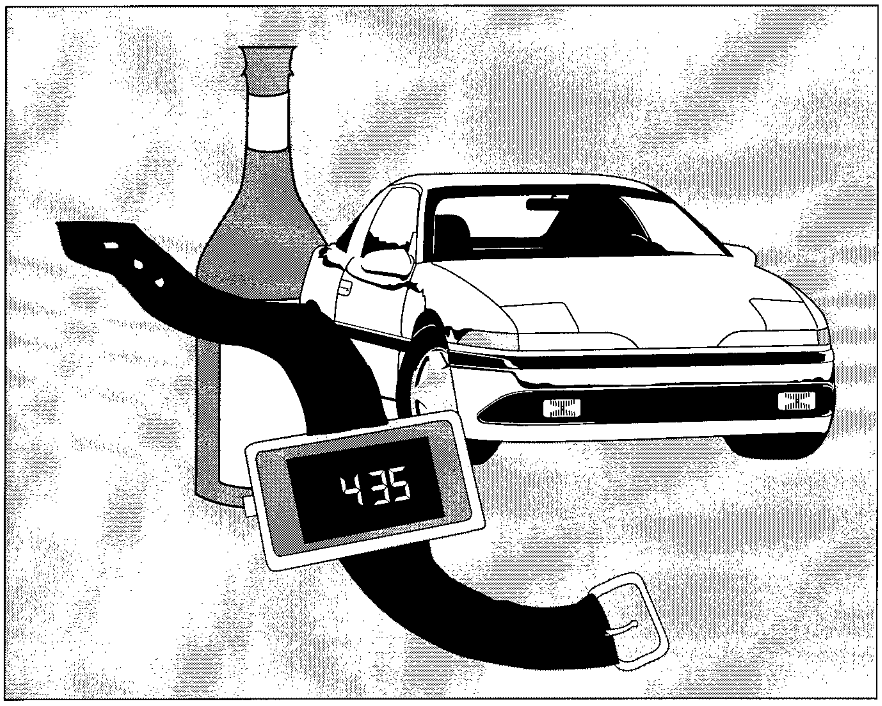


The algorithm developed at Rice University under an SDI IS&T contract can predict the position of a moving object, the density of a solution undergoing chemical changes, and the census of a growing population.

A professor at Rice University's Mathematical Sciences Department (Houston, TX) has developed an algorithm that estimates the solution to differential equations by using only a preliminary set of data. To control chemical process, the algorithm uses past trends to predict the properties of the resulting solution. In problems with five or more variables, the algorithm produces more reliable results than similar algorithms.

While the SDI IS&T program funded this project to track a satellite's path, the algorithm can project future events in any dynamic system. For example, it can predict the position of a moving object, the density of a solution undergoing chemical changes, and the census of a growing population. As a result of this innovation, the Rice professor is now working as a part-time consultant for Dynamic Matrix Control Corporation and Shell Development Corporation to improve the algorithms they use to control chemical processes.

Ceramics and Polymers Made from Sand



Silicon-based polymers, developed at the University of Washington in research sponsored by the SDI IS&T program, could be used to strengthen glass for bottles, make liquid crystalline polymers for watches, and serve as an electrically conductive film on windshields for defrosting. The University of Washington's process for making silicon-based polymers also could allow silicon-based materials to replace many petrochemicals.

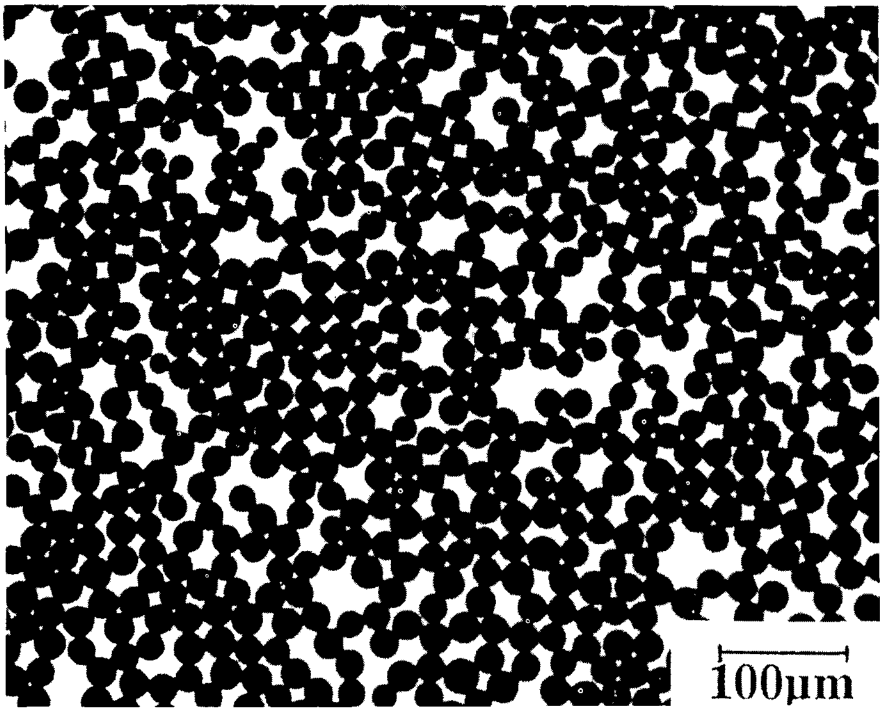
The University of Washington (Seattle, WA) has discovered, under an SDI IS&T contract, a series of chemical reactions that could start a new chemical and materials industry. The new chemical reactions will allow the chemical industry to make ceramic, silicon polymer, or silicon-based gels using silicon instead of petroleum (see sidebar).

Silicon, which is one of the most abundant, environmentally safe, and low-cost natural resources, is usually made from silica (sand). Despite this, production of silicon-based chemicals has been limited by the number of reactions available to prepare feedstock silicon compounds. In addition to many traditional materials, these feedstock silicon compounds could produce new polymers with ion conducting properties and liquid crystalline polymers. This could lead to a clear polymer that can be used as an electrically conductive film. Such a film could be used to make batteries and heated or electrochromic windshields. The University of Washington is seeking to license the process, with negotiations underway for several applications.

The University of Washington process produces silicon-based polymers through a basic reaction in which ethylene glycol and a caustic agent, such as potassium hydroxide, are combined at 125°C with silica. A simple equivalent to this reaction would be to dissolve beach sand with antifreeze and the commercial product, Liquid Plumr. The resulting solution can be easily processed by combining it with different diols, a class of alcohols, to produce the desired end product. This process may eventually cost less than the traditional metallurgical process in which feedstock silicon compounds are produced by heating silica at 1100° C.

Most common silicon compounds have four or six bonds in their structure, while compounds formed in the University of Washington process have five bonds. Silicon materials with the five-bond structure material are much more reactive. The increased reactivity of silicon eliminates hydrolysis from the production process, thus offering some advantages over sol-gel processing of glasses and ceramics. These advantages increase when generating multi-component glasses.

Structural Materials that Can Withstand High Temperatures



An optical micrograph of a Ni_3Al intermetallic composite reinforced with Al_2O_3 fibers. Intermetallic composites, developed by the Polytechnic Institute of New York under an SDI IS&T contract, can withstand temperatures of up to 1,300° C.

Higher operating temperatures increase engine efficiency, creating a demand in car, airplane, and spacecraft engines for metal-matrix composites that can withstand high temperatures. Also, hypersonic aircraft have surface temperatures higher than the thermal limit of current materials, creating a similar demand for composites with high temperature limits.

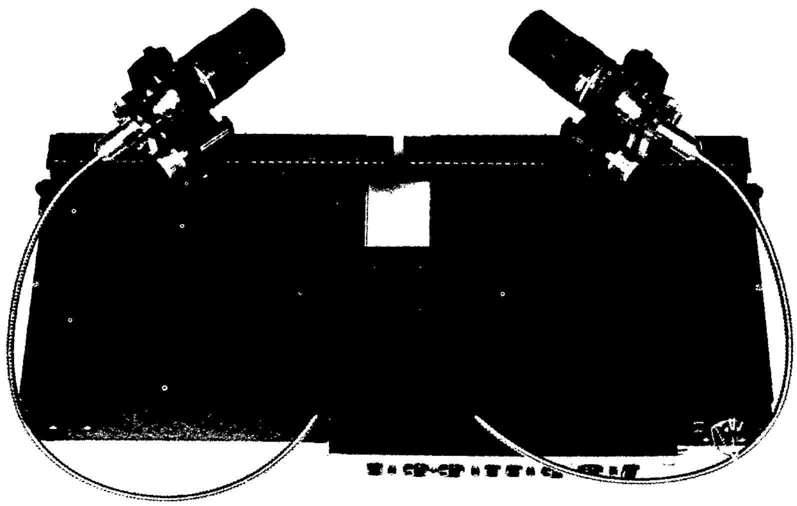
Researchers at the Polytechnic Institute of New York (Brooklyn, NY) are developing, under an SDI IS&T contract, lightweight intermetallic composites for potential use at temperatures ranging from 1,100° to 1,300°C (see sidebar). These low-density composites resist oxidation and maintain their strength at high temperatures, meaning SDI could build lighter, stronger satellites with the composites. The Polytechnic researchers have successfully pressure cast and tested several intermetallic composites with high fracture strength and modulus (stiffness).

Metal-matrix composites are traditionally made by powder metallurgy with particle reinforcement. Unfortunately, particle reinforcement provides low tensile strength and modulus. To make composites with higher strength and modulus, the Polytechnic Institute researchers use continuous fibers to reinforce metal-matrix composites. The researchers are investigating intermetallic composites of titanium aluminide (TiAl), iron aluminide (Fe_3Al), nickel aluminide (Ni_3Al), and niobium aluminide ($NbAl_3$). Fiber reinforcements are made of alumina (Al_2O_3), or Al_2O_3 and zirconia (ZrO_2).

Initial tests show that each intermetallic composite provides different advantages. For example:

- The nickel aluminide matrix has an average compression modulus of 280 billion pascals in a direction parallel to the fiber reinforcements, seven times the compression modulus of steel.
- The iron aluminide matrix resists oxidation and corrosion. In addition, it has a lower density than nickel-based alloys.
- The titanium aluminide matrix has low density (3.91 grams per cubic centimeter), high elastic modulus (175 billion pascals), and high tensile strength. It also resists creep, fatigue, and oxidation.

Analyzing Material Stress and Strain Using Diffraction Moiré

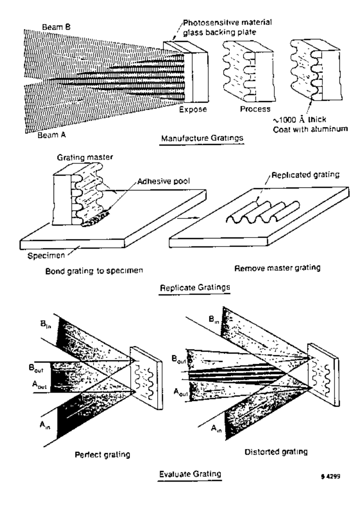


A diffraction moiré system that Idaho National Engineering Laboratory researchers developed under an SDI IS&T contract. Because it is portable, this system for measuring stress and wear of materials will move non-destructive inspection of construction materials from the laboratory to the field.

Diffraction moiré is a process used to analyze stress and wear on a material by creating an interference pattern on the material under analysis (see sidebar). In the past, researchers took hours to line up lenses, mirrors, and other components for a diffraction moiré experiment. Researchers at the Idaho National Engineering Laboratory (INEL) (Idaho Falls, ID), however, have made diffraction moiré devices more compact and easier to use by replacing conventional lenses and mirrors with fiber optic components. Because of their ease-of-use and compact size, the INEL devices expand applications from the laboratory to non-destructive inspection of materials in the field. Specific applications include inspection of welds, piping, and structural members.

The SDI IS&T program helped fund this work to develop a dynamic diffraction moiré system that instantly measures deformation of materials due to rapidly changing forces (such as those encountered by a rapidly accelerating missile interceptor). INEL has received several patents for its first diffraction moiré device, and has commercialized it through a license to Strainoptic Technologies (North Wales, PA). This first device was the size of a briefcase and weighed 40 pounds; INEL also has developed a lighter, hand-held system that, while more limited in application, acquires data more easily.

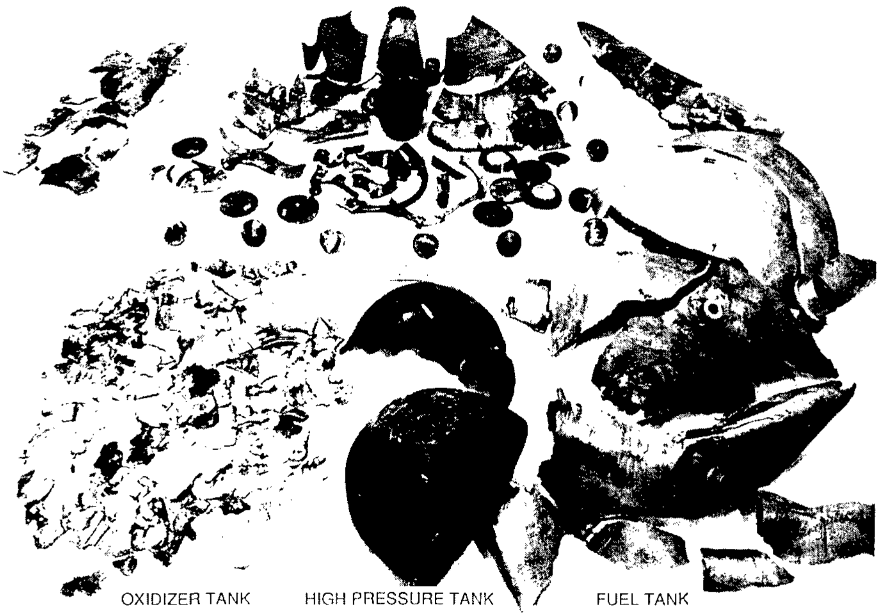
In diffraction moiré, incident light passes through a diffraction grating (an assembly of many narrow slits or grooves) placed over the material under analysis. The diffraction grating creates an interference pattern that interacts with the material, thus providing stress and wear data. Because the interference pattern interacts with an extended 2-D region of a material, researchers can map stress and wear for an entire region. In contrast, strain gauges only provide data at a specific point. Thus, diffraction moiré increases the chance of detecting localized defects in structures.



The interaction between light and a diffraction grating. After passing through the grating and interacting with the material under analysis, the resulting interference pattern provides information about stress and wear on the material.

SDI SPINOFFS
Military, Security, and Aerospace

Preventing Orbital Debris from Damaging Satellites



A photograph, taken after a hypervelocity impact test, showing the damage orbital debris can cause. The pictures in the sidebar show the original structure and the point of impact.

As part of SDI's Kinetic Energy Weapons program, the Defense Nuclear Agency (DNA) Kinetic Energy Weapon Lethality and Target Hardening Program (LTH-5) is studying the effect of hypervelocity impacts on various targets in space. By studying these impacts, the DNA group has collected data that will help develop weapons to destroy enemy missiles and methods to protect SDI's space-based platforms from enemy attack.

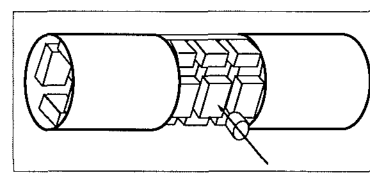
Another government program, the interagency Orbital Debris Spacecraft Breakup Modeling Program, is developing research plans to address the problems caused by orbital debris (see sidebar). As part of this effort, the group is developing spacecraft and target response models to:

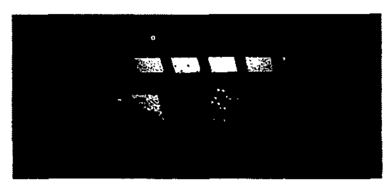
- Determine how much debris has been generated to date and the likelihood of collisions with space platforms
- Prevent accumulation of debris in the future
- Harden satellites so they will survive impacts with debris.

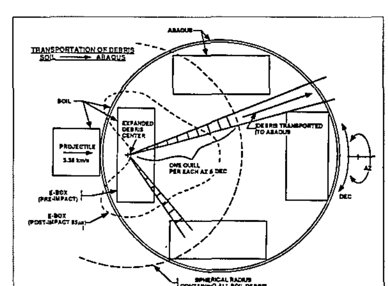
Because the research goals of these two programs are nearly identical (the DNA LTH-5 group is assessing the damage caused by hostile attacks, while the Orbital Debris Modeling Program is assessing the damage caused by random collisions), the DNA group has made its research available to the interagency Orbital Debris Spacecraft Breakup Modeling Program. The two groups work together through informal data-sharing arrangements, thus helping to solve a problem that soon could become a serious impediment to man's continued use of space.

Orbital debris, most often resulting from the breakup of satellites and their orbital insertion stages in orbit, is a growing problem that causes much damage to space platforms of all types. Because space debris develop high kinetic energy due to their velocities in orbit (up to 9 km/s), even debris as small as one millimeter in diameter can damage satellites. The data collected by the DNA LTH-5 program could provide needed information to help prevent this damage.

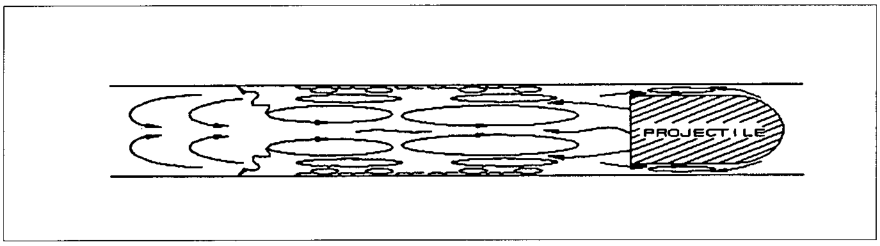
The LTH-5 experiments have measured the effects of hypervelocity impacts on ballistic missiles or space platforms. The data from these tests have been collected in a database, which is used to model and analyze the data, develop predictive models, establish criteria for what makes an effective weapon, and assess the lethality of weapons.







Improving Hypervelocity Gun Performance

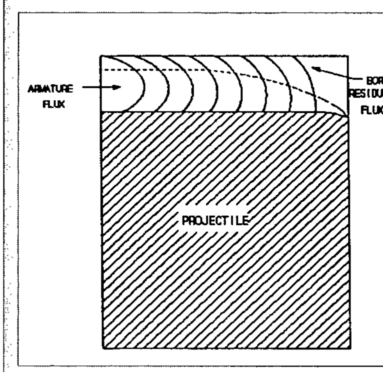


The gun bore in a hypervelocity gun. GT Devices modeled the interaction between the projectile and the gun bore to enhance the performance of hypervelocity guns for SDI.

Research done for the SDI IS&T and SDI SBIR programs has improved the performance of hypervelocity guns to the point where GT Devices, Inc. (Alexandria, VA) has found new applications for the guns. While these hypervelocity guns have obvious military applications, industrial-grade diamond production is a possible spinoff. To make the diamonds, two pieces of carbon are launched at high speeds in a collision path. The collision creates high pressure and temperature and, if heat is removed quickly enough, the carbon crystallizes into diamond. Another long-term application could be the direct launch of projectiles from large ground-based guns to space.

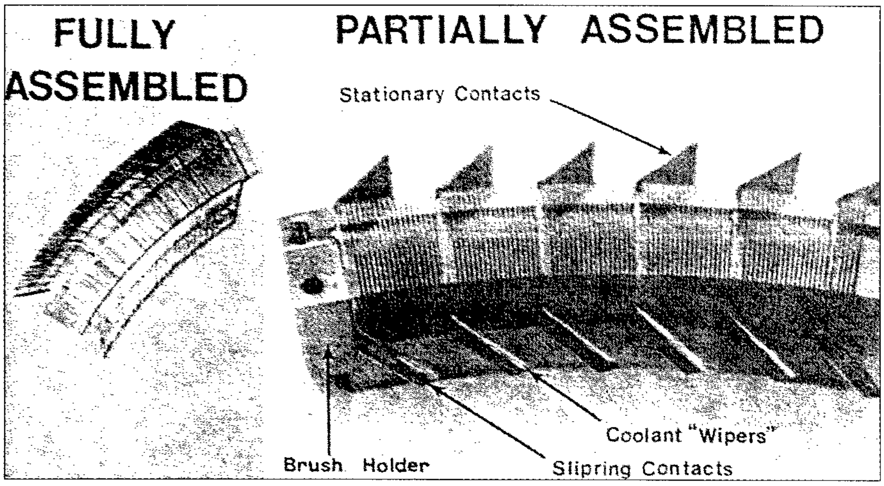
In addition to these applications, the research has led to an electric rocket — the plasma electro-thermal (PET) launcher. The PET launcher uses water as a propellant; water is forced through a carefully shaped rocket nozzle at very high velocity. While most rockets either consume large amounts of mass (such as in liquid propellants) or large amounts of energy (such as in ion engines), PET consumes moderate amounts of both, resulting in small rockets that have low fuel mass requirements.

This research conducted at GT Devices modeled the interaction between projectiles and gun barrel walls in hypervelocity (above 7 km/s) electromagnetic, electrothermal, and plasma mass launchers. In the gun bore-projectile interaction, the projectile sweeps gas, called the bearing, along with it and changes the geometry of the gun bore. The bearing usually hurts the performance of guns, but GT Devices uses the bearing to prevent the projectile from touching the gun bore walls (see diagram). At hyper velocities, contact between the projectile and the walls causes micro explosions that destroy the projectile and the gun tube. To prevent this contact, GT Devices studied the conditions in which the bearing does not squirt past the projectile. By keeping the bearing next to the projectile, GT Devices can use the bearing to prevent contact between the gun bore and the projectile.

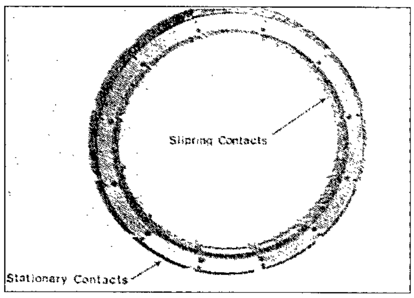


A close-up of the wall-projectile interaction. The curves at the top represent the bearing, a fluid layer that separates the gun bore walls from the projectile.

Aircraft Carrier Catapults, Sea Propulsion with Power Generator Technology



Current collector brushes developed by IAP Research Inc. during SDI SBIR contracts. Current collectors are used to power railguns for SDI, with other applications possible for the aerospace, marine, and transportation industries.

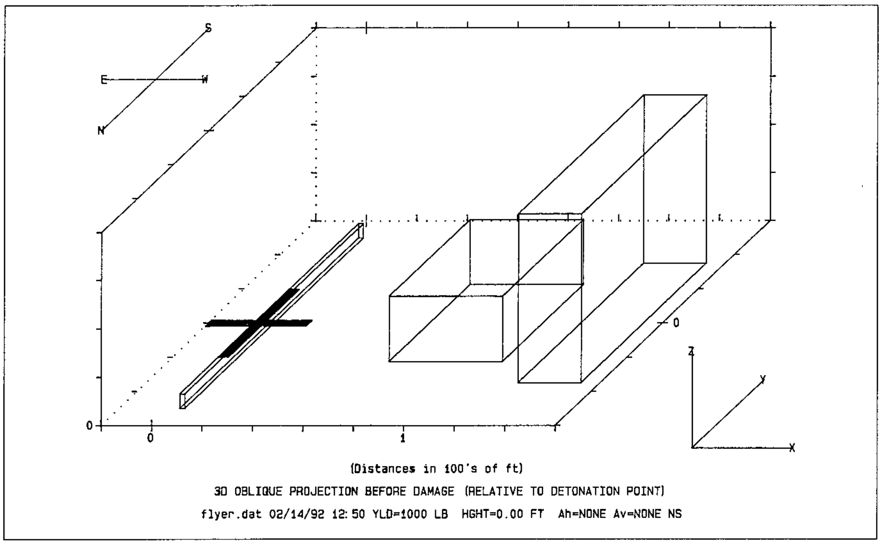


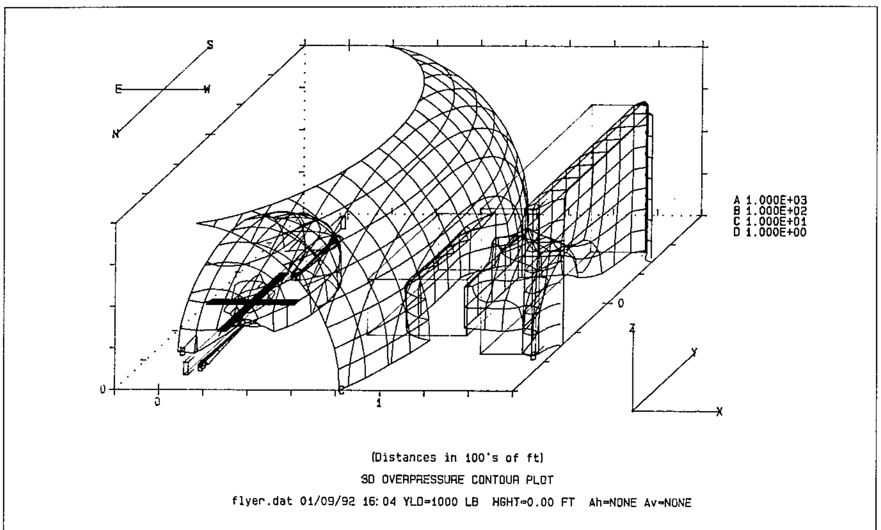
Because brush-type current collectors developed by IAP Research, Inc. (Dayton, OH) can operate in seawater, their DC power generators have marine applications for motors, launcher systems, and an aircraft carrier catapult system. IAP Research, Inc. developed and patented this technology under SDI SBIR contracts to design a DC power source for railguns. By improving heat removal and operating time, IAP's brush-type current collector technology overcomes the problems encountered with commonly used graphite brushes (see sidebar). Other potential applications for the brush-type current collector include lightweight, compact motors and generators for the aerospace industry; traction motors or current pickups for the transportation industry; and buss, slip joints, or disconnects for the utility and power industries.

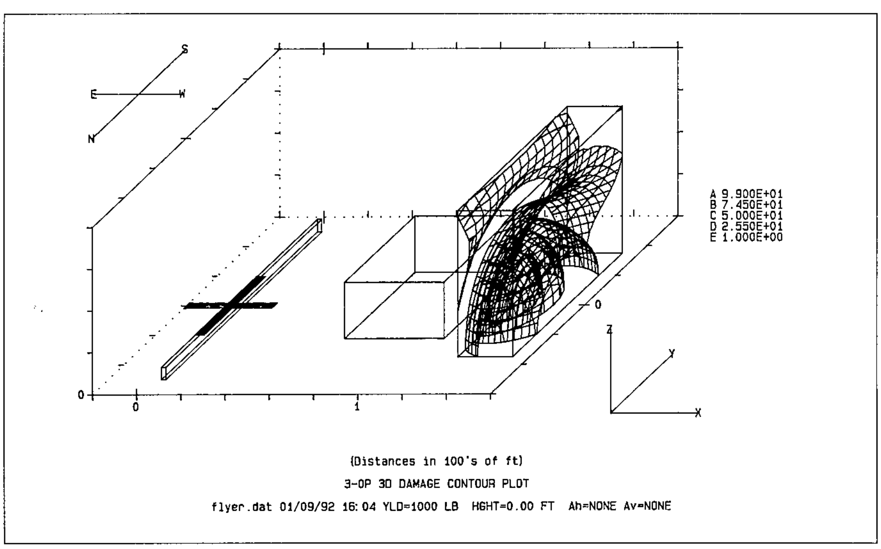
IAP Research, Inc. developed brush-type current collectors for multi-megawatt, continuous operation DC generators using copper, copper niobium, and finger-type composite brushes that minimize heat buildup. Using a film cooling process, brushes are cooled by applying water, liquid hydrogen, or liquid-nitrogen film where the brushes and slip ring meet. These brushes have low energy losses (an order of magnitude lower than graphite brushes) and excellent tracking capability (with a natural frequency of 5 kHz), are compact (one-tenth the size of graphite brushes), and can operate in harsh environments and rotate over 200 meter per second.

The IAP-developed generator has achieved a burst time of 30 seconds, the biggest technical challenge for multi-megawatt, continuous operation DC generators. Most multi-megawatt DC generators cannot operate for more than a few milliseconds due to excessive heating of the brushes. IAP has attacked the overheating problem using finger-type brushes and an independent cooling system. The finger-type brushes allow fluid to drip down each finger. Liquid hydrogen or nitrogen will be used as a coolant for most applications, since these liquids are already used in spacecraft. Ultimately, some type of pressure will force the liquid down the fingers, potentially by a pump or air pressure. The cooling system consists of a piezoelectric generator that controls a water droplet device. The water droplet device drips liquid onto the rotor very near the point of contact.

Limiting Damage from Explosions with Computer Modeling







The three pictures shown here are the graphical output of a simple HEXDAM™ simulation. The first picture shows the room before the explosion (the bomb is located in the dark "x" on the left side of the picture); the second picture shows the pressure waves caused by the explosion; and the third picture plots the damage caused by the explosion.

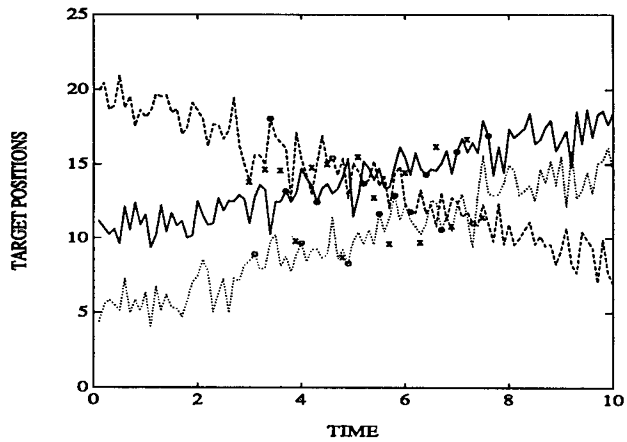
Engineering Analysis, Inc. (Huntsville, AL) has developed software that simulates explosions to assess their potential damage. The program, known as HEXDAM™, was created for SDI to model and predict the damage caused by nuclear explosions. Engineering Analysis has since enhanced the software to assess explosions caused by conventional army munitions and industrial accidents.

The HEXDAM™ program maps an area — such as a building or a campus of up to 200 structures — and determines the effects of an explosion within that area. This model also gives a 3-D analysis of the damage caused by primary explosions and associated secondary explosions. The effect of one structure shielding another also can be included.

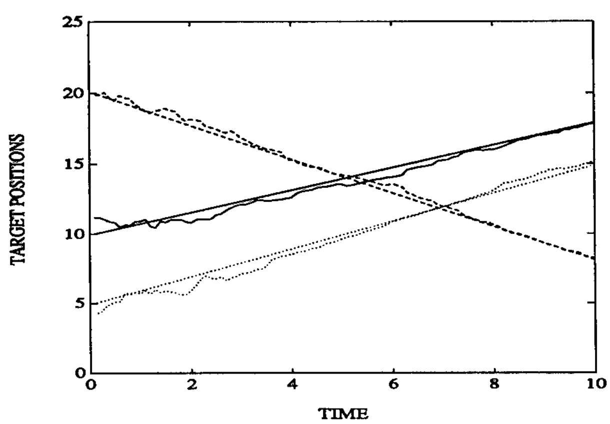
HEXDAM™ is now being used for two commercial applications. In the first application, chemical, oil and gas, solid propellant, and munitions factories — or any other facility that handles explosive materials — can use HEXDAM™ to plan the best way to minimize damage from an explosion. This model can simulate damage in different explosion scenarios. For example, the type of explosion, the location of the explosion, and the layout of the facility can be changed to find the best way to minimize damages. In the second application, physical security officers can use HEXDAM™ to simulate terrorist attacks, and thus limit the damage if such an attack occurs.

The Department of State plans to use the model for embassy security, and Exxon is using this product to re-create an explosion that occurred several years ago to determine its cause. An export license for the program has been approved. Thirty-two copies of the program have been sold worldwide.

Air Traffic Control, Collision Avoidance with Target Tracking Algorithm



Noisy target position measurements.



Estimated target positions (from SME filter).

Two plots of a target detection simulation using the Symmetric Measurement Equation filter developed by a Georgia Institute of Technology researcher under an SDI IS&T contract.

A researcher at the Georgia Institute of Technology (Atlanta, GA) has developed a new algorithm for estimating the future position of multiple ballistic missiles without the need to consider target/measurement associations or sensor-to-sensor correlations.

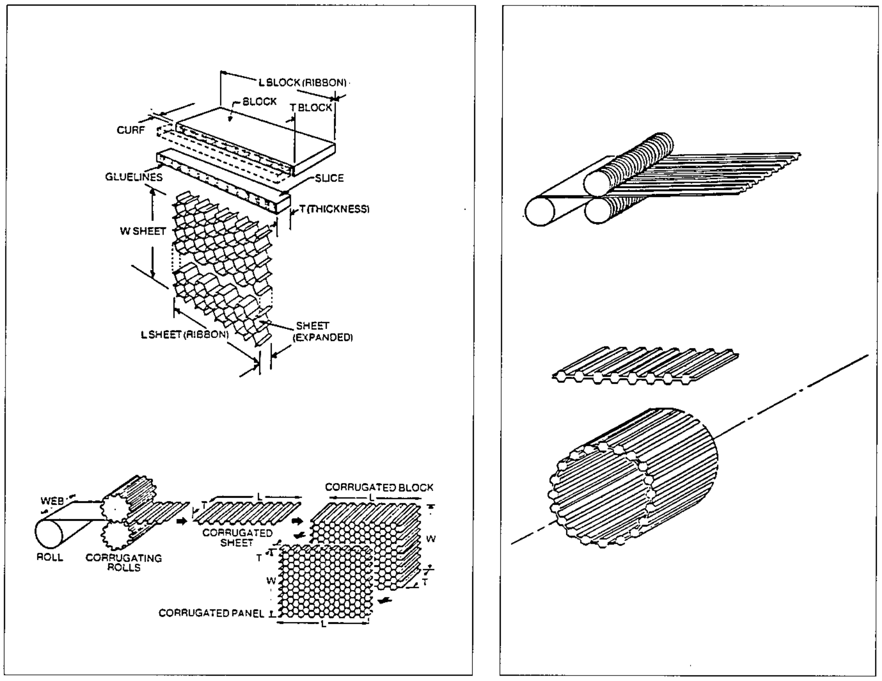
The new multiple target tracking algorithm, called the Symmetric Measurement Equation (SME) filter, was developed under an SDI IS&T contract. Recent work has resulted in a version of the SME filter that operates in environments where there are false and/or missing data.

In addition to missile tracking, potential applications of the new multiple tracking algorithm include air traffic control and ground and air collision avoidance systems. The United States Air Force and the National Science Foundation also have expressed interest in using the algorithm for intelligent control systems, distributed automated supply systems, manufacturing routing using computers, and chemical process control systems.

The SME filter is based on a standard dynamic state model for target trajectories and a measurement equation given in terms of sums of products of the original measurements. The filter substantially reduces the computational requirements to implement the tracking algorithm; in particular, the filter eliminates exponential (or factorial) growth in complexity as the number of targets increases.

As an example of filter performance, a simulation is shown in the accompanying figures. The simulation has three moving targets. In the first figure, the actual target positions are superimposed on the plots of the estimated target positions. The filter tracked the three targets for 10 seconds, despite 40 false and/or missing detections from sensor readouts. The second figure shows these false or missing data points; false detections are marked by X's, while missing detections are marked by O's.

Space Structures Benefit from Composites that Do Not Expand When Heated



Schematics of lightweight composites developed by Synterials, Inc. under SDI SBIR contracts. The composites, which do not expand when heated to temperatures of up to 600° C, can be processed into many different forms. Both the shapes shown here are designed to increase the ratio of stiffness to weight. The honeycomb structure (left) is best for long, extended structures such as an airplane wing, while the formed tube (right) serves as a pillar for structural support.

Under SDI SBIR funding, Synterials, Inc. (Herndon, VA) developed a process to make composite materials that do not expand when heated. This quality, known as zero coefficient of thermal expansion (CTE), keeps the material from expanding up to temperatures of 600° C. Under higher operating temperatures, the CTE is less than that of other materials.

The zero CTE composite would be ideal for space structures, which need to maintain dimensional stability as the spacecraft orbits from the light to the dark side of the earth, when the temperature varies from -100° C to +100° C. The composite also has applications on earth, such as in large paper mill rollers. Because friction in paper mill rollers generates much heat, the rollers need a material with near zero CTE so that they do not expand or break down during operation.

Synterials' lightweight composite material is made with graphite fibers in a quartz-like glass matrix. The glass matrix holds the graphite fibers in place, and modifies the CTE of graphite to balance it to zero. Individual graphite fibers are coated with boron nitride (BN) and amorphous silica by chemical vapor deposition (CVD).

The BN coating provides compatibility between the graphite fibers and the quartz-like matrix, and increases the strength of the final composite. The strength quadruples, with more than a tenfold increase in toughness compared to uncoated fibers. The amorphous silica increases composite strength and stiffness by permitting high fiber density and a uniform distribution of fibers in the composite.

The fibers are consolidated into a composite by a process known as roll-forming. Roll-forming provides a thin zero CTE sheet stock for lightweight, stiff, and stable space structures. Paper-thin sheets (1.2 to 2.0 mm thick) of this material can be further processed into many different types of space structures, such as tubes and honeycombs. The process can make a formed tube with sidewall stiffeners to better resist buckling, important for long thin-wall tubes.

SDI SPINOFFS

Science

Seeing Further into the Universe with Adaptive Optics

SDI's ground-based laser program had a technical problem that has plagued astronomers for centuries: atmospheric distortion. Through a telescope, stars (or, in SDI's case, targets in space) should look like bright individual points. Instead, they appear as blurry blobs because light passes through wind and temperature variations in the atmosphere. These variations distort light waves the same way ripples in water make pebbles on the bottom of a pond appear to wiggle. These atmospheric effects are what make stars appear to twinkle.

A laser beacon used in adaptive optics. Lasers are fired 90 kilometers into the earth's atmosphere to produce an artificial reference star. By measuring the distortion when atmospheric particles reflect the light back to the earth, researchers can compensate for distortion in images from space.

To solve this problem, SDI investigated adaptive optics, a system for correcting atmospheric distortion effects by using a reference star, deformable mirrors, and feedback control (see sidebar). SDI recently declassified its adaptive optics program, donating hardware, software, and technology to the National Science Foundation's (NSF's) civilian astronomy program. The technology, including hardware sent to the Massachusetts Institute of Technology's Lincoln Laboratory (Lexington, MA), may save civilian astronomers years of research and development needed to give earth-based telescopes the clarity of those deployed in space.

Traditionally, atmospheric distortion limits resolution no matter how large the telescope, making four-meter telescopes no better at resolving images than a backyard amateur's telescope. Adaptive optics, however, will provide new earth-based uses for extremely large, segmented main mirrors that previously served only to gather light (which allows astronomers to measure star brightness). An earth-based telescope using adaptive optics costs about $12 to $20 million, compared to $1.5 billion for the Hubble Space Telescope. (It should be noted, however, that space-based telescopes such as the Hubble Space Telescope are still needed to image high-energy, short-wavelength radiation — such as ultraviolet, x-ray, and gamma ray radiation — which is absorbed by the atmosphere.)

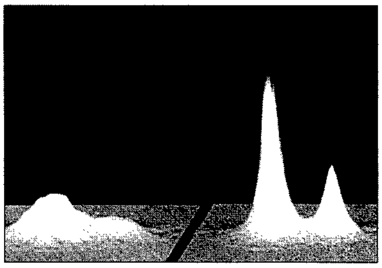
While working in the visible and infrared spectrum, a four-meter diameter segmented mirror with adaptive optics should provide a resolution 10 times better than other earth-based telescopes, and equal to the Hubble Space Telescope. Newer, larger telescopes may provide a resolution two to three times better than the Hubble Space Telescope.

Since declassification of adaptive optics technology, Lincoln Laboratory researchers have installed a 69-channel adaptive optics system on the 60-inch telescope at the Mt. Wilson Observatory in southern California. SDI funded installation of this system to broaden the performance database for operational adaptive optics systems. The NSF will fund further work at the Mt. Wilson adaptive optics system.

Before using adaptive optics to reshape distorted light from a star, one must first find out how much the atmosphere has deformed the star's image. Because atmospheric conditions are constantly changing, the deformable mirror also must constantly change shape --hundreds of times per second. In one approach to measuring atmospheric distortion, researchers electronically monitor the distortions of a bright star lying close to the object in which they are interested. By feeding the bright star's signals into a computer, a set of actuators bend the rubber mirror to compensate for atmospheric distortion.

Unfortunately, most celestial bodies don't reside next to a bright reference star. In an alternate method, researchers fire a laser into the sky to create an artificial reference star. Researchers can shoot an intense laser beam 90 kilometers into the earth's atmosphere, and then measure the distortion of laser light reflected back to earth.

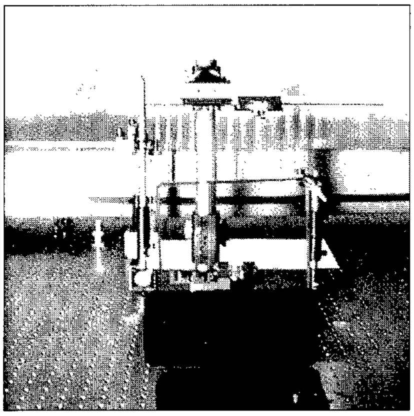
The University of Hawaii developed a third approach under SDI funding, in which researchers increase the observed brightness of a reference star by amplifying leftover photons from the reference star. With this method, astronomers can use a reference star 2.7 magnitudes fainter than previously needed. Because researchers can use dim reference stars, the method offers low cost and high throughput.



An uncompensated image of the star Castor (left) and a compensated image (right). Adaptive optics resolve images from space 10 times better than other earth-based telescopes.

Protecting Scientific Equipment with the Raman Holographic Edge Filter

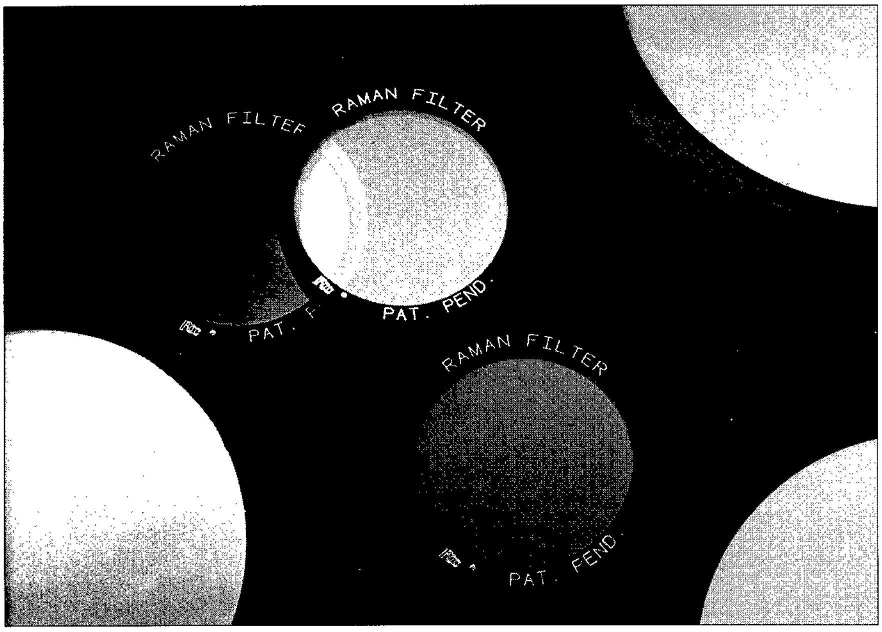
Physical Optics Corporation (POC) (Torrance, CA) is producing high-density ultraviolet holographic filters to protect space platforms from ultraviolet lasers. A group of spinoff products already on the market is the Raman Holographic Edge (RHE) filter series.



A test performed on a holographic filter. Here, ultraviolet lasers are directed at, and reflected off, the filter.

The RHE filters, which POC developed during SDI SBIR contracts, filter out harmful light and allow important data to pass through (see sidebar). By filtering out unwanted light, the RHE filters not only can protect space platforms from ultraviolet light, but also can improve the efficiency of Raman spectroscopy. Raman spectroscopy analyzes the composition of various substances based on their interaction with light. The improved efficiency eliminates the need for double or triple spectrographs, allowing the user to work with a single spectrograph and increase throughput. With improved efficiency, the ultraviolet filter can, for example, be used for spectroscopic imaging of the sun.

POC currently markets its filters for spectroscopic applications, ranging from energy conservation to laser mirrors. Several U.S. laboratories including Sandia, Los Alamos, and Lawrence Livermore, and many universities in the U.S. and Japan use the RHE filter.



Raman holographic edge filters. Physical Optics Corporation developed these filters under SDI SBIR contracts to help protect SDI surveillance sensors from ultraviolet radiation. The filters also can be used in Raman spectroscopy to reject unwanted and often harmful light.

POC makes its RHE filters by putting a holographic recording on a polymer overlay. These filters, which have a very high optical density and narrow bandwidths at multiple wavelengths, provide excellent protection against ultraviolet radiation. The holographic grating of the cured polymer surface layer reflects optical radiation of selected wavelengths and transmits other wavelengths. This technology is particularly useful for edge filters intended to reflect ultraviolet radiation. In addition to developing filters for ultraviolet applications, POC has extended the technique to make filters for visible and infrared regions of the spectrum.

Holographic edge filters offer numerous advantages over traditional filters made using multi-layer dielectric coatings. For example, the POC filters:

- Are less expensive
- Provide a sharper spectral cutoff because the edge transition region is narrower
- Have a more uniform wavelength transmission profile that does not show the fine-scale oscillations encountered with multi-layer coatings
- Can be applied to almost any smooth surface, including curved surfaces.

Long-term stability of the polymer coatings is a major concern for the filters. Laboratory tests indicate the coatings are thermally stable and resistant to conventional liquids and solvents. To protect the filters from physical damage and moisture, POC can sandwich the filters between scratch-resistant cover plates.

Astronomical Accuracy with the Large Optics Diamond Turning Machine

A researcher working on the large optics diamond turning machine. Originally built at Lawrence Livermore National Laboratory to produce the high-power optics for SDI's Alpha laser, the diamond turning machine also has been used to produce high-precision optics for telescopes.

Lawrence Livermore National Laboratory (LLNL) (Livermore, CA) has developed a large optics diamond turning machine (LODTM) that can machine finish, with no polishing necessary, deep cone-shaped mirrors up to 1.65 meters in diameter. With the ability to finish mirrors to an accuracy of 0.025 microns (0.025 millionths of a meter), diamond turning of optical components is hundreds of times more accurate than standard numerically controlled turning machines.

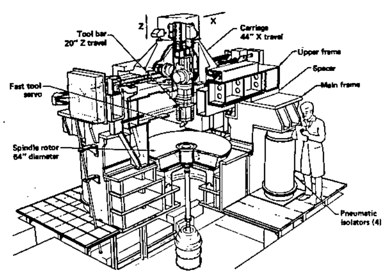
LLNL originally built the LODTM to produce the high-power optics for SDI's Alpha laser. High-energy laser systems such as the Alpha require reflective optical elements of large aperture (several feet in diameter) with non-spherical shapes. Multi-surface, multi-pass laser designs like the Alpha also require a very accurate form and fine finish for each reflective surface. The LODTM produced Alpha optics in October 1987, and is now fabricating a complete set of spares.

In addition, the LODTM recently machine finished the 0.5 meter secondary mirror for the Keck Telescope being built in Mauna Kea, Hawaii. With an average deviation from perfection of one-fortieth of the average wavelength of visible light, the uniquely shaped beryllium mirror will be used to detect infrared light. With this degree of accuracy, scientists will be able to locate and study a planet orbiting another star. Built atop a 14,000-foot extinct volcano, the Keck will be the world's largest telescope and provide astronomers the clearest view of outer space from the earth's surface.

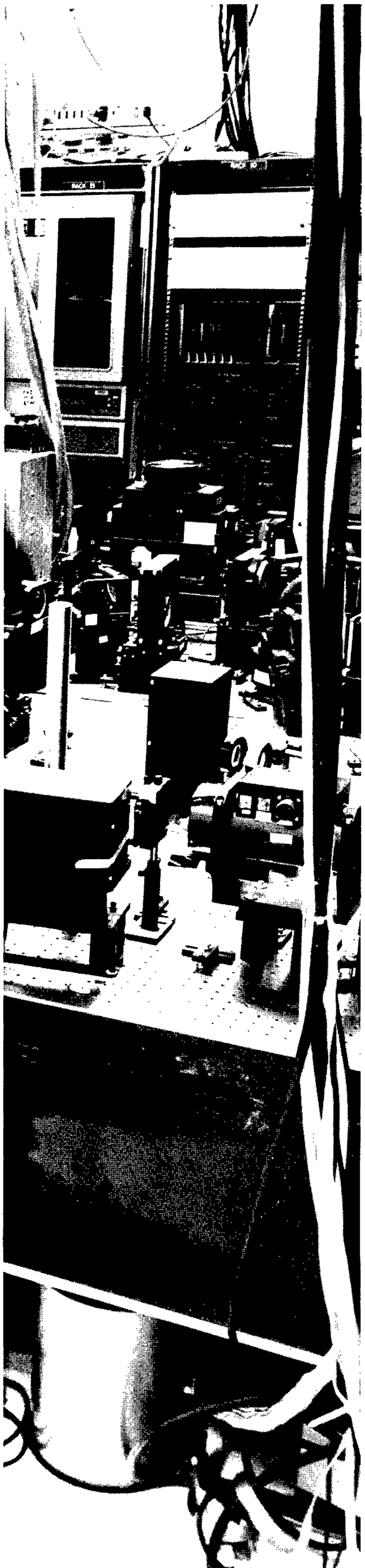
Diamond turning machines also have finished optical components of x-ray microscopes and NASA's grazing-incidence x-ray space telescopes. These parts required elliptical and parabolic 5 cm diameter shapes that were machined to a tolerance of 0.05 microns.

In the LODTM, the optical surface is direct machined by single point diamond-tip turning. The LODTM makes possible the manufacture of conical mirrors that are symmetric in only one plane. This is accomplished by a tool bar that is driven up and down (Z coordinate) and moved horizontally with a carriage (X coordinate). Laser interferometers continuously make all the measurements necessary to locate the diamond tip tool in the X and Z coordinates.

Symmetry in the machine design allows several sources of error to be self-canceling. Liquid flows through the machine to maintain thermal stability of the structure to a uniformity of 0.0005° C.



A schematic of the large optics diamond turning machine.



CONCLUSION

How to Access SDI Technology

This report, with information on more than 50 SDI-sponsored technologies, has provided only a small sample of the contributions SDI technology can make to industry. Many more spinoffs have happened, and many more will — showing that SDI can not only enhance America's national security but also its economic competitiveness.

SDIO recognizes that continued success in transferring technologies from their original purpose to a commercial application will take work. To that end, the Office of Technology Applications is structured to help technology users take advantage of SDI research results. SDI's on-line technology transfer database, the Technology Applications Information System (TAIS), provides the primary link between technology users and SDI researchers. The TAIS has no users' fees (the only cost is for the modem phone call), although you must be certified by the Defense Logistics Agency (DLA) to access the TAIS (any U.S. corporation or citizen may receive certification). To do this, you need to complete a militarily critical technical data agreement and send it to the DLA. When you receive DLA certification, you will also receive TAIS access codes and directions on how to use the TAIS database.

For further information about these Department of Defense certification procedures, and to receive the militarily critical technical data agreement form, call the Defense Logistics Service Center at (800) 352-3572. If you are a federal agency employee, you may obtain TAIS certification by sending a request on official letterhead to the Office of Technology Applications, as follows:

Strategic Defense Initiative Organization
Office of Technology Applications
SDIO/TNI
The Pentagon
Washington, DC 20301-7100

The Office also has a staff of technology transfer professionals available to help you with individual needs. Assistance with using the TAIS, as well as more information about the Office's technology applications reviews, outreach services, demonstration projects, or specific technologies of interest, is available by calling (703) 693-1563. We encourage calls, and will do anything we can to help you access SDI technology.

APPENDIX
SDI's Technology Programs

SDI's technological innovations come from a variety of sources, from focused research programs that develop specific components of a strategic defense system (such as directed energy weapons; kinetic energy weapons; sensors; and command, control, and communications) to programs that develop generic technologies of value to SDI.

In the second category, the SDI Innovative Science and Technology (IS&T) program funds generic research and development in universities, national laboratories, and industry to foster revolutionary advances in technologies needed by SDI. Since private industry often resists funding high-risk ventures, the IS&T program is a valuable way to nurture infant technologies that might not be developed otherwise. Although the outcome of any one high-risk innovation sponsored by the IS&T program is unpredictable, successful IS&T-sponsored research is likely to have commercial applications because it focuses on producing technological breakthroughs. To maintain this focus on technological breakthroughs, IS&T sponsors research in six general categories: high-speed computing; sensing, discriminating and signal processing; space power and power conditioning; directed and kinetic energy concepts; materials and structures; and propulsion and propellants.

The SDI Small Business Innovation Research (SBIR) program is another program designed to spark breakthrough innovations for SDI. The SBIR program was created by the Small Business Innovation Development Act of 1982 to encourage small firms to participate in Federal research contracts. SBIR contracts are divided into two phases, both of which are awarded competitively. In Phase I, SDI awards about $50,000 to study the feasibility of an innovative idea that supports the SDI mission. Phase I projects can then compete for Phase II contracts of approximately $500,000 to develop the ideas into prototypes. Small businesses can use their SBIR Phase I and II results to develop commercial applications with other sources of funding.

The SDI Technology Applications Information System (TAIS) contains information about research opportunities through these programs. In addition, you can find out more by calling (703) 693-1563.